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Operations Research and Economics Division

ANALYSIS OF SURVEY DATA
PART III
(PROTECTION ANALYSIS OF NFSS STRUCTURES)

FINAL REPORT R-OU-154/196

Each transmittal of this document outside the Department of Defense must have prior approval of the Office of Civil Defense (Research).

Prepared for
Office of Civil Defense
Department of Army - OSA
Under
Contract No. OCD-PS-64-56
and
USNRDL Contract No. N-228-(62479)-66109
Task Order 64-200(2)
Work Unit 1115B

RESEARCH TRIANGLE INSTITUTE · DURHAM, NORTH CAROLINA

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by

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Operations Research and Economics Division

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PREFACE

Research under OCD Work Unit 1115B began under Contract No. OCD-PS-64-56 and was managed by the Shelter Research Division of OCD. Management responsibility for Work Unit 1115B was transferred to the U. S. Naval Radiological Defense Laboratory (NRDL) on 12 May 1964 and a new contract, N-228-(62479)-66109, was executed by NRDL. Final Report R-OU-154, Cost and Protection Analysis of NFSS Structures, dated 22 January 1965, reported the research completed under the original OCD contract. This report, R-OU-154/196, Analysis of Survey Data, Part III (Protection Analysis of NFSS Structures), describes the research accomplished under both contracts and therefore supercedes Final Report R-OU-154.

ABSTRACT

Key facilities (electric power plants, water treatment plants, hospitals, fire stations, and communications facilities) were analyzed to identify recurring special shielding problems and to determine the importance of massive, irregular special equipment in affecting radiation shielding for certain critical operations. It was found that interior contents are significant, but only in a limited number of facilities. A computer program, written in GAT symbolic language for use on a Univac 1105 Computer, for calculating the protection factor (PF) in irregularly shaped structures with numerous building construction changes was developed and is recommended for use in key facility PF calculations.

A statistical study of National Fallout Survey Phase 2 building structural characteristics extracted from OCD files is reported. Included in the 844 buildings analyzed are 1030 basement shelter areas, 262 first story shelter areas, and 838 upper story shelter areas. The modal value for basement sill heights is 5 feet; whereas 80 percent of the sill heights for the first stories are from 2 to 3 feet; and for upper stories 90 percent are from 2 to 3 feet. Parallel partitions occur in 51 percent of the basement shelter areas, 68 percent of the first story shelter areas, and 78 percent of the upper story shelter areas. Cross partitions occur in 761 of the 2130 shelter areas. There were 493 areaways reported in 337 building parts. Sixty-six percent of the areaways are 30 percent or less of the building side length and 83 percent are 5 feet or less wide.

"Area factors" are multipliers used to estimate the fraction of the total floor area offering protection greater than a predetermined value. The area factors used in the NFSS do not vary with structural details of the building. Several shortcomings of these approximate area factors are discussed. Analyses of shelters with only roof contribution and of shelters with both ground and roof contribution are presented. Methods of determining more nearly correct area factors for each situation are given for use with simplified hand computational procedures. Lastly, for more exact computations, it is recommended that the shelter area be calculated by computing PF's at several offcenter locations and determining graphically the areas which reach a prescribed PF.

A study was made to determine the effect on the PF of a shelter of ingress of fallout particles through open windows. PF's in the basement and third story of several hypothetical buildings were compared with "effective PF's" of the same areas assuming ingress fallout. The areal mass densities of ingress fallout in the neighborhood of apertures were 2 percent and 20 percent of the fallout density outside each hypothetical building. A change in PF of 10 percent or less was noted in more than 70 percent of the 128 cases. A change of 25 percent or greater was noted in only approximately 10 percent of the cases.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

LIST OF TABLES (CONT'D)

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

Chapter 1

Summary

I. INTRODUCTION

This constitutes the final report of research completed under OCD Work Unit 1115B, Analysis of Survey Data, Part III (Protection Analysis of NFSS Structures). This research was performed under office of Civil Defense Contract No. OCD-PS-64-56 and Naval Radiological Defense Laboratory Contract No. N 228(62479)66109 [Task Order 64-200(2)]. The contractual scope of work for Work Unit 1115B is included as Appendix A.

The specific objectives of the Work Unit were to:

(1) Identify recurring special shielding problems and to determine the importance of massive, irregular special equipment or interior contents in ascertaining the shelter capability for certain critical operations in "key facilities"1/ in a fallout situation.

(2) Recommend modifications to computer programs for analyzing the protection afforded by key facilities.

(3) Analyze the importance of areaways, interior partitions, and aperture sill heights in the computation of the protection factor (PF) by categorizing NFSS Phase 2 data for these characteristics.

(4) Determine the effects of combinations of ground and roof contribution on the usable shelter area of a building.

(5) Evaluate the effect of ingress of fallout particles through open windows on the PF of a shelter.

1/ The structure types considered as "key facilities" were electric power plants, hospitals, fire stations, and communications facilities.

II. FINDINGS AND CONCLUSIONS

A. Key Facilities

A review of literature available for key facilities was performed to determine the recurring construction and operating characteristics. This review helped to identify both the locations which must be manned for the operation of the facility and the type and arrangement of equipment which contributes to structure shielding.

Theoretical shielding calculations were performed to evaluate the factors involved in shielding afforded by large machinery and to determine if PF computational methods such as the Engineering Manual (Reference 1) are adequate to treat such shields. It was concluded that, generally, interior contents can be accounted for by homogenizing the material over the projected area it occupies and including this material with that of an appropriate exterior wall or interior partition. These data can then be used directly in the Engineering Manual computational procedure.

Field analyses of key facilities reflecting various geographic and construction differences were conducted in Fort Lauderdale, Florida; Tulsa, Oklahoma; Long Beach, California; and Lynn, Massachusetts. Operating stations for functions that would require manning during and after an attack were identified and used as detector locations for PF computations. The required locations were generally found to be in the building parts of lightweight construction that were not near the center of the building. Only two of the 26 facilities surveyed had PF's of 40 or more according to the NFSS on the stories of interest. Eight of the facilities had PF's that were higher than 40, as calculated by the more accurate[2/] RTI Key Facility Computer Program.

2/ e.g., more nearly agreeing with the Engineering Manual method.

The following conclusions were drawn from the analysis of key facilities:

(1) The RTI Key Facility PF Computer Program is adequate for analyzing offcenter detector locations in irregularly shaped buildings.

(2) Interior contents are significant, but only in a limited number of facilities.

(3) PF's in the location of required operations are quite different from those of the few facilities surveyed in the NFSS.

(4) The ability to change the fictitious building size in each azimuthal sector yields a PF calculation as much as 25 percent greater in irregularly shaped buildings.

B. Categorization

An analysis of building structural characteristics contained in NFSS Phase 1 data was previously reported in Reference 2. Phase 2 data, which included information on aperture sill heights, areaways, and interior partitions, were not available during the time period reported in Reference 2. Therefore, this study completes the evaluation of all building characteristics reported in the NFSS for an original sample of 1541 buildings. Only 844 buildings of the parent sample of 1541 were surveyed in the NFSS Phase 2. Data for building parts (complex buildings in the NFSS were divided into rectangular parts) and shelter areas (stories of building parts that have adequate protection; i.e., PF 40), classed by protection factor, are of interest in determining the correlation between structural data and protection from fallout radiation.

There were 1030 basement shelter areas, 262 first-story shelter areas, and 838 upper-story shelter areas, giving a total of 2130 shelter areas reported. A total of 493 areaways were reported in 337 building parts. Of these areaways,

66 percent were in lengths of 30 percent or less of the building side length, and 83 percent were 5 feet wide or less. Sill heights reported for basements had a mode of 5 feet; whereas, 80 percent of the sill heights reported for first stories were from 2 to 3 feet, and 90 percent reported for upper stories were from 2 to 3 feet. Interior partitions were defined in the NFSS Phase 2 as either "parallel" or "cross" partitions. Parallel partitions (partitions, such as in corridors, that extend essentially the complete length of a building) were reported for 51 percent of the basement shelter areas, 68 percent of the first-story shelter areas, and 78 percent of the upper-story shelter areas. Cross partitions (short partitions such as those separating adjacent rooms) were reported for 761 of the 2130 shelter areas.

Information on the frequency of occurrence of structural characteristics is also very important in the design of PF computer programs. For example, these data indicate a need to include areaways in PF computations, and their variable length suggests azimuthal sectors as the best method of approach. The number of sill heights at the two-foot level emphasizes the importance of being able to compute the direct radiation which would penetrate the one foot of aperture that is below detector level. Large numbers of interior partitions were reported in Phase 2, but their locations must be quantified for use in calculating roof contribution.

C. Area Factors

Area factors represent fractions of total floor areas which offer protection greater than a predetermined value. For determining gross estimates of the total number of available shelter spaces by machine methods, the area factor approach used in the NFSS Phase 1 Computer Program was excellent. However, a careful

analysis of each building should be made before final determination of the actual shelter area is made. Several sources of significant error using the NFSS area factor method are: (1) cases in which center PF's are lower than offcenter PF's due to mutual shielding or variation in grade level; (2) the effect of special characteristics of interior partitions, floors, and apertures; and (3) shelters with predominantly roof contribution.

Simple methods of determining usable shelter area for shelters with all roof contribution, and with both ground and roof contribution, are presented. In a related study, a simple technique for determining shelter boundaries in a building by making only one PF calculation in the shelter area was developed and reported in Reference 3. The technique accounts for nonuniform ground contribution as well as the characteristics discussed in Chapter 5.

D. Ingress of Fallout

A study was made to determine the effect on the PF of a shelter of ingress of fallout particles through open window. PF's in the basement and third story of several hypothetical buildings (2,000 and 10,000 square feet) with and without ingress were compared. The areal mass densities of ingress fallout per square foot used were 2 percent and 20 percent of the fallout density outside each hypothetical building. These amounts were chosen in order to show the extreme effects of very little and large amounts of ingress fallout. Comparisons of buildings with and without ingress fallout indicated the following:

(1) As expected, ingress fallout was found to have less effect on the initial PF (without ingress fallout) in the larger buildings.

(2) Ingress fallout has a greater effect on the higher initial PF's. Ingress fallout is especially significant in basements due to the higher initial PF's found in the basement areas.

(3) The offcenter detector data showed little difference from data for the center.

(4) Contributions from the stories above and below the detector story accounted for a maximum of 30 percent of the ingress contribution in buildings with 20 psf floors, and less than 10 percent in buildings with 80 psf floors.

(5) For upper stories, ingress fallout equal to 2 percent of the outside concentration causes a maximum of 10 percent decrease in initial PF.

(6) The 20 percent concentration reduces the upper story initial PF by as much as 30 percent in a building with interior partitions and by approximately 50 percent without partitions.

(7) A maximum reduction of initial PF of approximately 55 percent is noted for basement in both buildings sizes.

(8) A change in PF of 10 percent or less was noted in more than 70 percent of the 128 cases. A change of 25 percent or greater was noted in only approximately 10 percent of the cases.

Chapter 2

Analysis of Key Facilities

I. INTRODUCTION

Following an attack on the United States, the availability of essential goods and services is the key to survival and recovery. One purpose of this study has been to identify recurring special shielding problems and to determine the importance of massive, irregular equipment or interior contents in ascertaining the shelter capability for certain critical operations in a fallout situation. The structure types considered as "key facilities" were electric power plants, water treatment plants, hospitals, fire stations, and communications facilities.

A review of literature available on facilities of this type was performed to determine the recurring characteristics of key facility construction and operation. The results of the analysis of electric power plants, water treatment systems, and hospitals are reported in Section II below. Consideration of shielding by interior contents expected in key facilities led to calculations to evaluate the effect of apertures in shielding material which either penetrate the shield completely, or which form cavities within the shield. These findings are contained in Section III and Appendix B. A field survey of selected facilities was also conducted to identify special shielding problems and to determine the importance of interior contents. This survey is discussed in Section IV.

The findings of these analyses are incorporated in the PF Computer Program recommended in Chapter 3 for key facilities.

II. CHARACTERISTICS OF KEY FACILITIES

A. Electric Power Plants

Electric power generating plants may be grouped into three categories, with similar shelter problems within each category (Reference 4). These categories are:

(a) Hydroelectric,

(b) Steam turbine, indoor type, and

(c) Steam turbine, outdoor type.

Internal combustion driven plants supply such a small percentage of the nation's total power that they are not considered. Hydroelectric plants generally have areas that are suitable for fallout shelter with only supplies needed. The older indoor type steam plants generally have areas that could be converted into fallout shelters while most outdoor type steam plants do not have areas that could be converted into fallout shelters without additional construction.

It has been found (Reference 5) that representative hydroelectric plants of the TVA system (Chickamauga and Fontana) have electrical control rooms which have a protection factor of less than 100 and thus could not be occupied continuously by the same man during heavy fallout. However, areas with protection factors approaching 1,000 are available at Chickamauga, and the inspection tunnels within the dam at Fontana may approach a protection factor of 10,000. The presence of very good shelter in the facility and the relatively small amount of control required by a hydroelectric plant means that the problems of operating in a fallout field are not so numerous and do not require the extensive protection factor studies which are required at some other types of facilities.

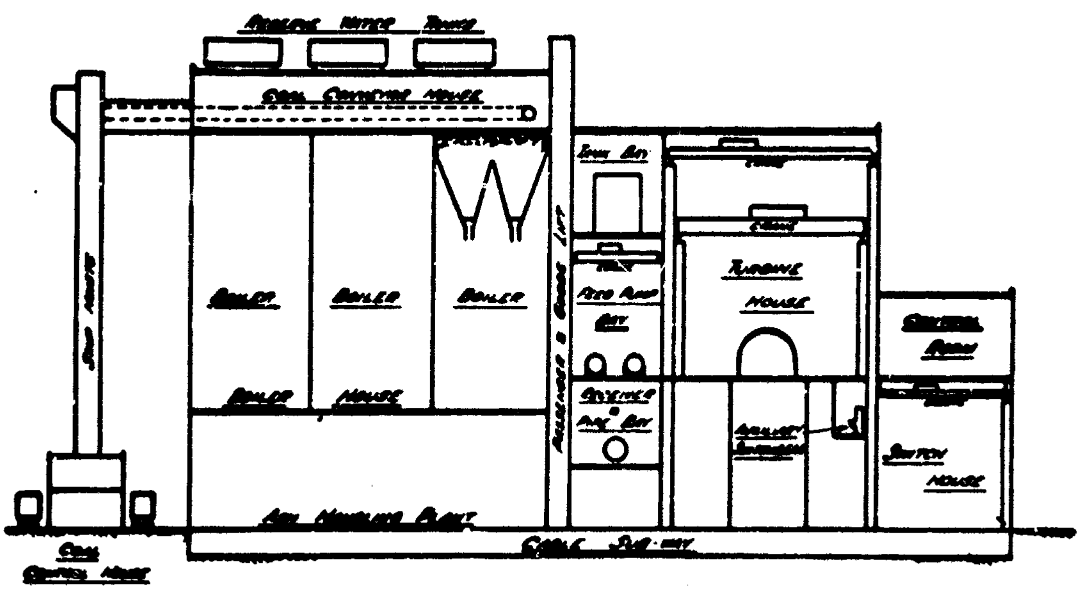
While the older types of outdoor steam plants have places suitable for protection from fallout, these spaces are generally located at points which are remote from the operating stations. Particularly in these older plants, constant attendance at operating stations is required (Reference 4). Figures 1a to 1e illustrate typical arrangements of the indoor type of steam turbine plant (References 6 and 7). These figures illustrate that while the location of the control room varies from plant to plant it is often located so that one or more sides of the room are shielded by a complicated maze of pipes, furnaces and boiler structure, etc. However, it is shown also that the control room is often in a small adjoining building with a conventional office building type construction on three sides. In some of the older plants it is necessary for a man to be in the turbine room to monitor the turbine operations and to manually adjust the steam valves when a unit is being brought on line.

In the outdoor type steam plant, the control room is often suspended several feet in the air either between the boilers or on a light steel frame on the side. With the room thus suspended, it offers very little protection from fallout radiation. In this type plant, even when the control room is on the ground, it is of light office building type construction offering very little protection.

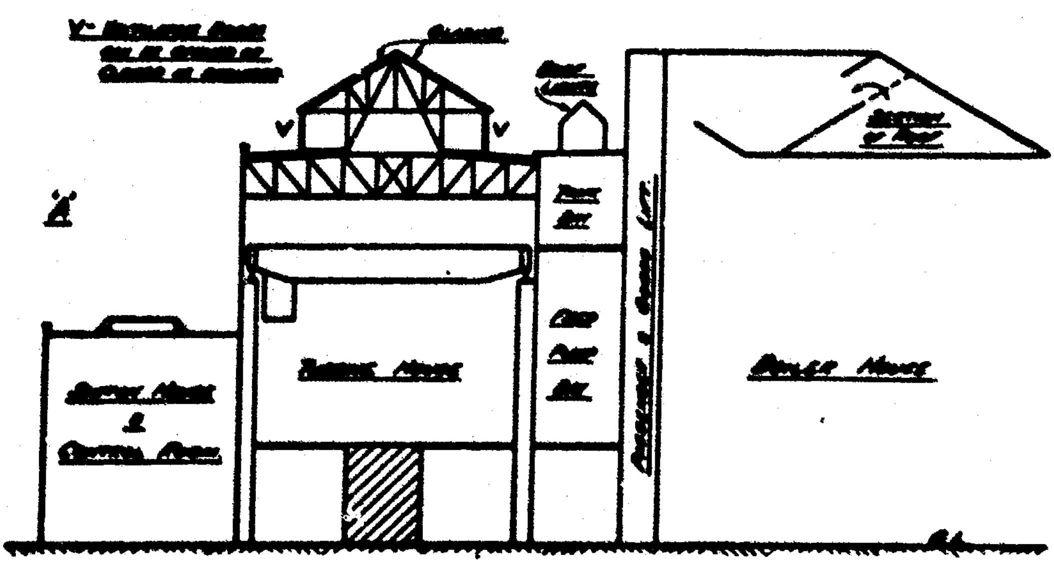
In any coal fired steam plant, there would be problems with the fuel supply in a fallout situation. First, the deliveries of coal would be disrupted, making the plant dependent upon on-hand reserves for operation until delivery is resumed by the transportation industry. Also, in an intense fallout field, the full utilization of on-hand reserves would not generally be possible even with automated systems. This is because bulldozers or a dragline manned from a lightly constructed building could not be operated to move the reserve

FIGURE 1

Typical Arrangement of Power Stations
(Source: References 6 and 7)

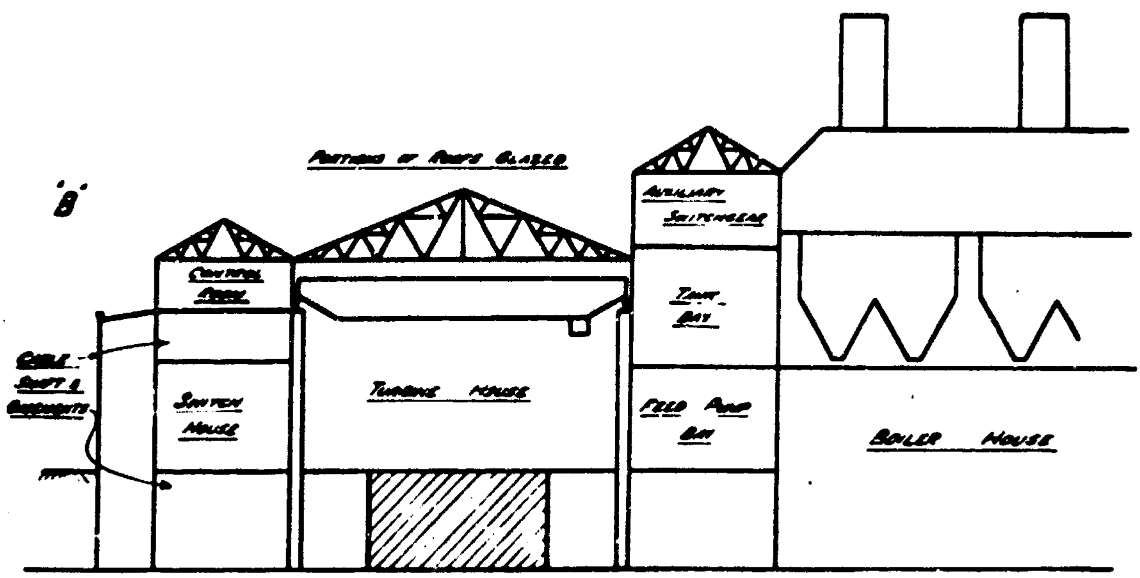


1a

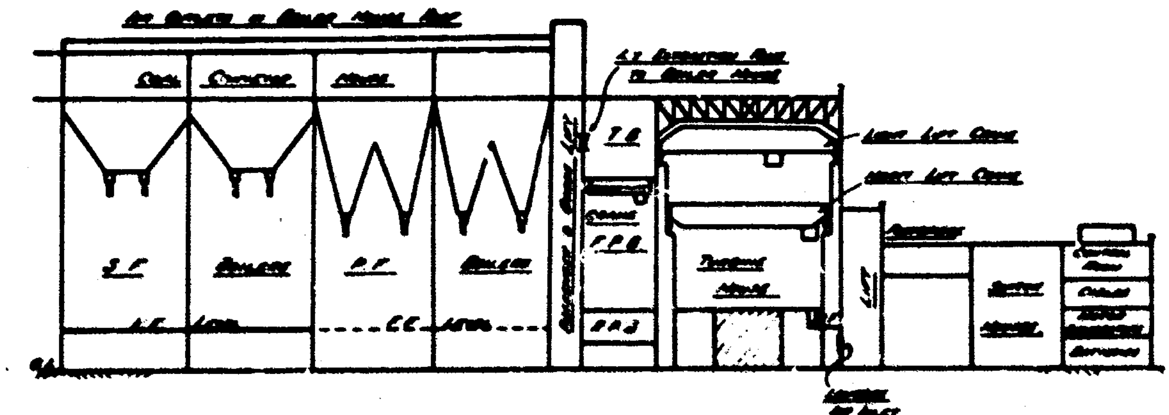


1b

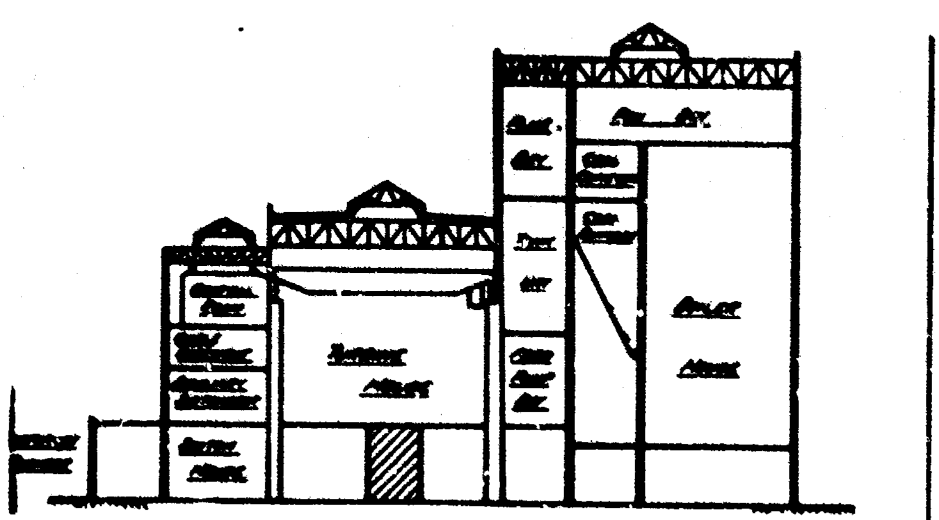
FIGURE 1 (Cont'd.)



1c



1d



1e

pile into the automatic conveyer system. For example, the Kingston plant (Reference 5) has coal stored in the bunkers, which when full are adequate for a 34-hour operation of units 5 through 8 and a 45-hour operation of units 1 through 4.

Therefore, the considerations necessary in electric power plants are:

(1) Location of potential shelter areas in indoor type steam plants,

(2) Provision for adequate shielding for control points in the indoor plants,

(3) Location of potential shelter near outdoor type steam plants, and

(4) Provision for decontamination of reserve coal handling areas and of the entire outdoor type steam plants (Reference 8).

B. Water Treatment Systems

As stated in Reference 9, "....the major problem of water system operations in fallout areas would be the exposure of water works personnel to radiation and the availability of adequate shelter at the plants.

"Secondary damage would occur to the treatment plant if it were left running when operating personnel took shelter elsewhere and electric power continued to be available. After 1 to 3 days, filter beds would clog and cause flooding and short circuits in electrical equipment. In the post-shelter period, the time to repair this damage might be the limiting factor in making the water system fully operational."

The problem of water works operation in a fallout environment is complicated by the fact that there are many points within the plant which must be manned. In a typical treatment plant (Reference 9), the points which must be manned (although not continuously) for the operation of the facility were:

(1) Pump control panels,

(2) Chemical feeder control panels,

(3) Chemical feeder rooms, and

(4) Filter operating galleries.

Typically these points are dispersed throughout the plant; personnel must spend some appreciable time in very modest shelter (even if they do not have to venture out of doors to reach some operation point). This would be true when assumed that it is impractical to make the entire treatment plant a shelter, or to create a shelter at each operation point. Both assumptions are generally valid for existing facilities. Thus, the personnel operating a water treatment plant in a fallout environment (even after an initial shutdown during the period of maximum dose rate) require high PF fallout shelter. Such shelter may often be found in the "pipe gallery" section of the filter building (Figures 2a to 2c) and, even in small filter plants, certain locations may make excellent shelter (References 10 and 11).

Therefore, the considerations necessary for making water treatment plants operable postattack are:

(1) Location of potential shelter areas,

(2) Determination of feasible improvements to make these areas very good shelter,

(3) Determination of protection factor of other areas which personnel must traverse or occupy periodically to operate the plant, and

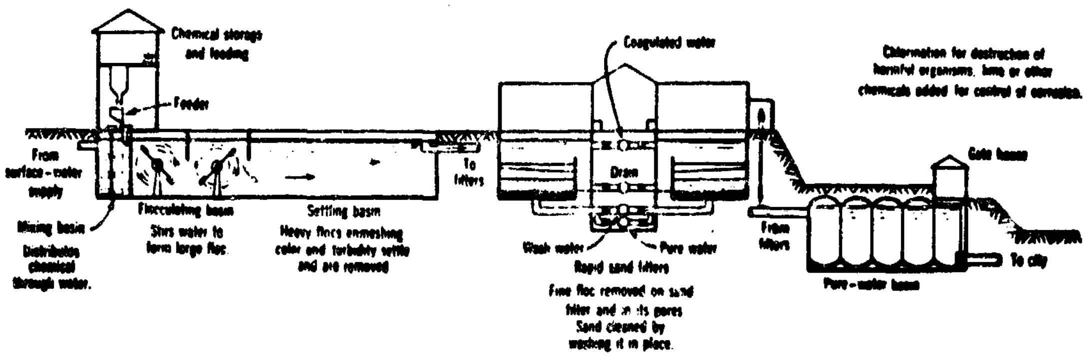
(4) Making feasible improvements in these areas as necessary.

C. Hospitals

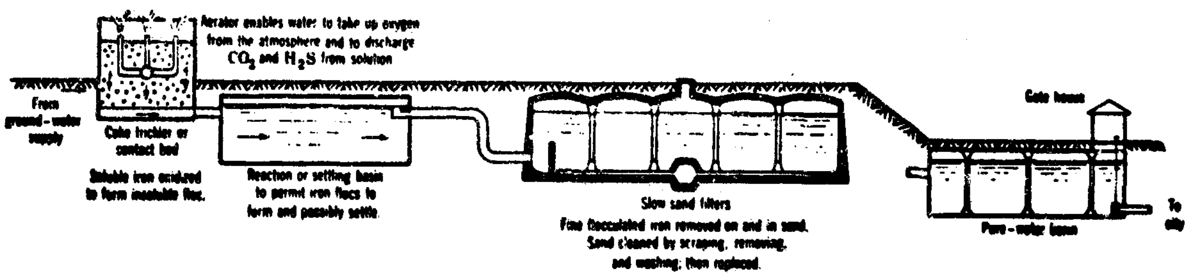
Hospitals and the skilled staffs of hospitals would certainly be a key to the postattack recovery of a population. However, the manner in which this resource would be used is an important consideration in determining the critical engineering characteristics of hospital structures which would require modification for operation in a fallout situation.

FIGURE 2

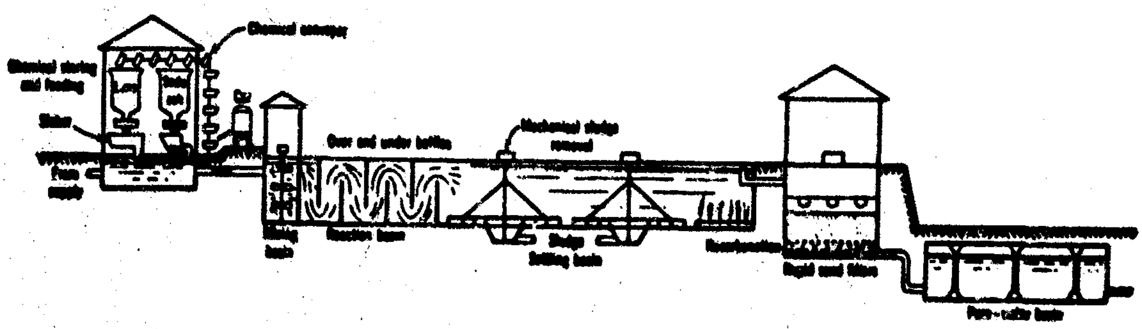
Typical Arrangement of Water Treatment Plants
(Source: Reference 11)



a. Filtration plant including coagulation, settling, filtration, chlorination, corrosion control, and pure-water storage.



b Deferrization plant including aeration, contact treatment, filtration, and pure-water storage.



c. Softening plant including addition of softening chemicals, settling, recarbonation, filtration, and pure-water storage.

In studying the effects of a series of attacks on the United States, it is stated that (Reference 10):

> "The hospitals do not survive quite in proportion to the general population. However, Public Health Service Personnel estimate that about 75 percent of the people occupying hospital beds could be released without suffering deleterious effects. Thus, after the rehabilitation of those surviving the injuries received in the attack, the hospitals and medical personnel should be able to handle the normal peacetime case load....
>
> "Consider the case of Connecticut after the HM attack. Damage assessments of the NREC indicate that there would be 1.2 million blast casualties (including immediate facilities) and that only 593 hospital beds would be available immediately after the attack. Of the casualties, 189,000 would survive without treatment. Experience with battle casualties (Beebe and DeBakey) indicate that about two-thirds of the remaining injured would die the first day and 83 percent would die within two days. Use of the Public Health Service Rapid Calculation for Use in Estimating Health Resource losses indicates that about 2,500 of the 5,000 doctors in Connecticut would be among the blast casualties. If a doctor can care for 10.5 casualties per day (Beebe and DeBakey), the surviving 2,500 doctors could care for 26,000 casualties the first day and 52,000 in two days (provided hospital facilities are available, which they are not.) Herzog estimates that medical care would decrease the number of fatalities among those treated by 15 percent. Eighty-three percent of the total casualties are in areas having fallout intensities in excess of 1000 r/hr at 1 hour and have little prospect of reaching medical facilities in any event. Finally, medical personnel should remain in good shelter during the attack and shelter phase rather than exposing themselves to treat casualties. Their skill will be essential to the long-term rahabilitation of the surviving population."

Thus the shelter problems in hospitals are of two types:

(1) Locate or develop really good shelter for the professional staff of the hospital, and

(2) Locate shelter as good as possible for the patients.

Acquiring shelter for the staff could involve surveying the hospital, surveying nearby buildings or special facilities, improving shelter space in the hospital or nearby, and constructing shelters.

Locating shelter for patients will perhaps involve some unique considerations. For example, problems of quarantine or of immobility may require certain patients

to remain on a particular story or in a particular area, although higher PF shelter might be available. Also, although 75 percent of the patients might be released without suffering deleterious effects, it seems reasonable to assume that as a rule, all patients would have to find shelter within the hospital. It has been shown (Reference 12) that shelter with PF lower than that included in the NFSS could be of substantial benefit. Thus, the protection factor of the entire area of a hospital should be determined. Marking, in the usual NFSS manner, might not be necessary or desirable. However, complete protection factor information should be available to the director of operations of the hospital.

III. SHIELDING AFFORDED BY LARGE MACHINERY

A. Introduction

In order to properly anticipate what portions of a structure might serve as a shelter against fallout radiation, it is necessary among other things, to determine the mass barrier thickness between the area being considered and the presumed sources of the radiation. In most cases, this mass thickness is composed of wall, floor, and roof weights. However, there are cases where the effective wall weight may be many times that of the structure alone. These are the cases where heavy machinery and/or other massive items lie between the source and shelter area.

B. Theoretical Calculations

Theoretical shielding calculations have been performed to evaluate the factors involved in shielding afforded by large machinery and to determine if

PF computational methods such as the Engineering Manual (Reference 1) are adequate to treat such shields. These calculations are contained in Appendix B. The equations were formulated and applied to what was considered to be a worst conceivable case. A summary of the procedures used is given below.

Of primary interest in the calculations was consideration of ducts or holes passing completely or partially through massive items. For instance, what is the shielding afforded by a generator or motor recognizing the cooling passages along the armature? Or, what is the effect on its shielding characteristics of a draft tunnel through the base of a furnace? In performing the calculations, ducts were considered to be straight cylinders which go completely through a bulk shield (furnace, generator, motor, etc.) in a direct line of sight from the source to the detector. This assumption serves to emphasize the effect of ducts through the bulk material and thus makes any conclusions regarding them and the radiation received through them conservative.

It was assumed that the bulk material would be adjacent to an exterior wall. The inside surface of this wall was considered as the source plane for the calculations. The radiation emitted from this exterior wall was assumed to have a cosine distribution with reference to the forward direction.

Radiation incident on the bulk material was separated into various components:

(1) Radiation that penetrates solid material only,

(2) Radiation that streams down a hole in a shield without coming in contact with solid material,

(3) Radiation that enters a hole and passes down the hole after scattering from the material surrounding the hole, and

(4) Radiation which starts out either in a hole and passes into solid material, or starts out in solid material and penetrates to a hole subsequently passing down the hole out of the shield.

There is radiation, of course, which will undergo multiple scattering and thus may start out in a hole, penetrate to solid material and be scattered back into a hole subsequently streaming down this hole out of the shield. However, radiation of this type is much less important than the aforementioned because of the low probability of multiple interactions. Therefore, this radiation was neglected in the considerations. Scattering of radiation from the side walls of a duct was calculated using albedo theory. The transmission of radiation through solid material was calculated by determining a barrier factor for this material exposed to a cosine distribution.

The characteristics of heavy machinery vary considerably; the example was chosen to emphasize the importance of ducts through machinery and voids within it. The relative contribution to dose of each component of radiation was computed and compared with the dose contributions due to other components. The particular example chosen assumed a machine approximately 20 feet thick with a metal content of approximately 30 percent of the total volume. Passing through the machine were assumed to be 30 six-inch diameter ducts in 100 square feet of front shield surface.

C. Findings and Conclusions

The results of the calculations show that the largest component of dose received behind a bulk shield is due to transmission through the solid material. The other contributions to radiation dose (due to duct streaming and scattering into ducts, etc.) were found to give a radiation dose contribution which is

smaller than the dose due to transmission through solid material by more than an order of magnitude. The results of these calculations were compared with experimental data on bulk shielding of fission gamma radiation. The comparison indicated the theoretical approach is conservative; the calculations predict a higher relative dose through the ducts than is experimentally measured.

It was therefore concluded that the shielding afforded by bulk material can, to a good approximation, be accounted for by homogenizing the material over the volume it occupies and including this material with that of an exterior wall or interior partition in front of which it is located. The details of this treatment are shown in Section IV,"Application of Results", of Appendix B.

IV. FIELD SURVEY OF KEY FACILITIES

A. Survey and PF Computational Procedures

The field analyses of key facilities reflecting various geographic and construction differences were conducted in Fort Lauderdale, Florida; Tulsa, ' lahoma; Long Beach, California; and Lynn, Massachusetts. Facilities surveyed in each city were selected in consultation with the Local OCD Director, who also obtained permission to survey the facilities.

Operating stations for functions that would require manning during and after an attack were identified and used as detector locations for PF computations. The required locations are generally found to be in lightly shielded areas that are not near the center of the building.

Structural data necessary to compute protection factors at the locations of the essential operating functions were obtained by reviewing building plans, when available. Of the 26 buildings surveyed, building plans were obtained for 21. Included in the shielding analysis were machinery and other interior contents interposed between the contaminated planes and the detector locations, as well as all interior partitions, exterior walls, etc., which are commonly used in PF computations. The buildings were often of irregular shape and construction.

Contaminated planes which would affect each structure were determined by examining Sanborn Maps and by visual inspection of structures for which maps did not exist. In all cases, sketches were made of the surrounding areas to verify the Sanborn Map data and to supplement it with new construction data, height of terrain, etc. Peculiar contaminated planes such as filter tanks at water plants, cooling water streams at power p' nts, etc., were included in the analysis of the facilities.

Because Engineering Manual computations are quite extensive for complex structures, a computer program designed primarily for key facilities was developed and is described in Chapter 3. Special computational problems associated with key facilities which this program can handle are:

(1) Arbitrary offcenter detector locations which are handled by

(a) Reporting planes of contamination and structural details relative to the offcenter detector rather than the center of the building part, and

(b) Changing the building width and length within each sector to ref the proper distances to contaminated planes rather than having to use a single rectangular approximation of the entire building part.

(2) Shields that do not shield an entire wall, which are handled by changing the partition (or machinery) and/or exterior wall mass thicknesses, as required, for each azimuthal sector.

In addition to handling these special problems associated with key facilities, the program also has the following capabilities which are useful for evaluating buildings of any type:

(1) Sill heights are reported to the nearest foot,

(2) Aperture percentages may change by azimuthal sector, and

(3) The contributions from each plane of each sector are reported separately for each contributing story, thus permitting a complete analysis for potential shielding improvements.

B. Findings

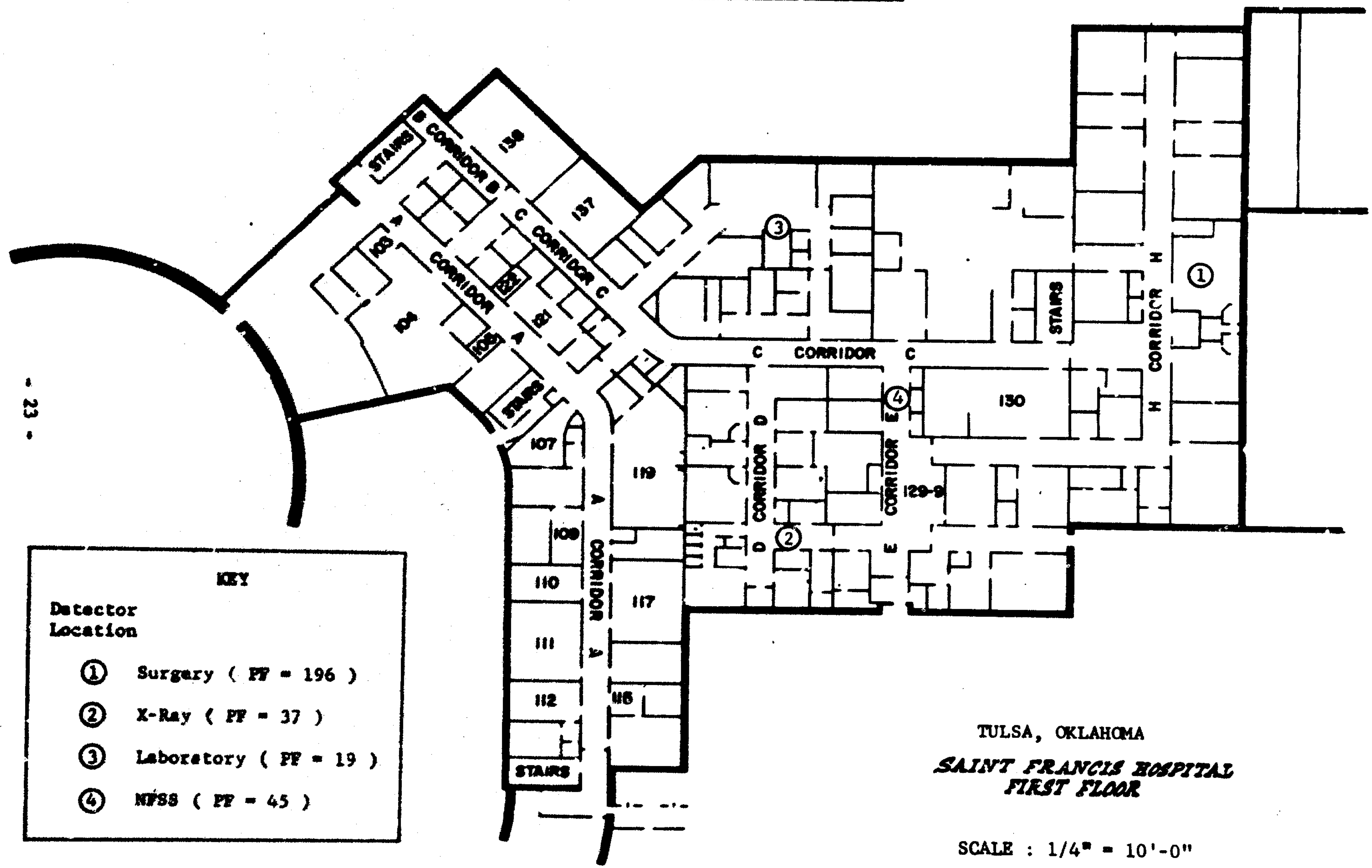
Figure 3 shows the Saint Francis Hospital, Tulsa, which is an excellent example of unusual shape, unusual partition locations, and requires offcenter detector locations. The location of the NFSS Phase 1 detector is shown as well as three important locations chosen by RTI and hospital personnel: operating room, X-ray area, and a laboratory. As shown on the figure, the RTI PF's were 196, 37, and 19, respectively, and the NFSS Phase 2 PF was 45 for the center of the building. An analysis of irregularly shaped structures such as this indicated that the computed PF can increase by as much as 25 percent if the building width and length can be changed in each azimuthal sector. The PF always increases using this procedure as long as the original rectangular approximation reported by the Architect-Engineer (AE) is smaller than the maximum dimensions of the irregular building. This is almost always the case because AE's were directed to ignore small wings and irregular protrusions.

Table I shows protection factors for each of the key facilities, without interior contents, and if they were significant with interior contents also. The NFSS PF category for the center of the building is also shown when available. Because of the minimum space requirements for 50 persons in the NFSS, and lightweight construction, only two areas of interest in the 26 key facilities had PF's as high as PF 40 calculated in the NFSS.

Descriptions of the buildings surveyed are contained in Appendix C. Exterior photographs, an indication of the essential functions performed, and the type of construction are reported.

FIGURE 3

Example of Key Facility Detector Locations



TULSA, OKLAHOMA

SAINT FRANCIS HOSPITAL
FIRST FLOOR

SCALE : 1/4" = 10'-0"

TABLE I

Protection Factors of Key Facilities
at Essential Operating Locations

	PF With Contents	PF Without Contents	NFSS PF Category[3/]
Fort Lauderdale, Florida			
1. Five Ash Water Treatment Plant	12		
2. Ft. Lauderdale Water Dept. (Dixie Plant)	16		
3. Southern Bell Telephone Company	300		
4. Municipal Court Building (Police)	7.0		4
5. Florida Power and Light Company	4.5		
6. Fire Station Number 1	4.6		
7. Holy Cross Hospital	165		
Tulsa, Oklahoma			
8. Tulsa Water Treatment -			
Boiler Control	9		
Turbine Control	4		
New Filter Control	9		
Old Filter Control	13		
9. St. Francis Hospital -			
Surgery	196		2
X-ray	37		2
Lab	19		2
10. Fire Alarm Building	16	15	
11. Tulsa Power Plant -			
New Control Room	35	29	
Old Control Room	33		
Dispatcher's Office	31		
12. Tulsa Police Communications	52		
Long Beach, California			
13. Long Beach Gas Compressor Plant	4	4	
14. Alamitos Generating Plant - Control Room	37		
15. Long Beach Water Treatment Plant (New Pumping Plant)	7		
16. Long Beach Fire Alarm Building	16	13	
17. Long Beach Community Hospital - Operating Room	45		
18. General Telephone -			
Trouble Shooting Board	312	223	
Switchgear	690	81	
Information & Long Distance Operators	80	76	
19. Long Beach Police Communications	52		
Lynn, Massachusetts			
20. New England Telephone Company	142		
21. Lynn Community Hospital	22		
22. Lynn Police Headquarters	10		
23. Fire Communications Center	6		
24. Lynn Waterworks (Walnut St. Pumping Station)	17		
25. Massachusetts Gas and Electric Company, Lynn Station - Boiler House	16		
26. Massachusetts Gas and Electric Company, Lynn Station - Control Room	14		

[3/] Buildings that do not have shelter as high as PF category 2 (PF 40 or more) are not included in the NFSS.

C. Conclusions

1. The RTI Key Facility PF Computer Program is adequate for analyzing offcenter detector locations in irregularly shaped buildings.
2. Interior contents are significant in a limited number of facilities.
3. PF's in the location of required operations are quite different from those of the few facilities surveyed in the NFSS.
4. Changing the fictitious building size in each azimuthal sector can increase the computed PF by as much as 25 percent in irregularly shaped buildings.

Chapter 3

Computer Program for Key Facilities

I. INTRODUCTION

Key facilities, such as power plants, water plants, etc., are usually of nonuniform construction, irregular shape, and in some cases they have significant interior equipment. The computer program described in this chapter is based on the Engineering Manual (Reference 1) and was developed to compute the PF's of key facilities (see Chapter 2). It is designed to be very flexible and permit the user to account for special building and contaminated plane details.

Contributions from setbacks below the detector and limited planes of contamination (including areaways) are calculated for the detector story and the stories above and below the detector story. The effects of apertures, interior partitions, mutual shielding, and building geometry are included. Roof contribution is not calculated and must be done by hand and added to the machine computed ground contribution.

Major differences between the program and other programs used in surveys of structures are:

(1) more azimuthal sectors are allowed and building construction changes (walls, partitions, and apertures) may be accounted for in each sector,

(2) shielding by interior contents can be computed,

(3) major changes in vertical construction can be handled by using a zero floor weight at the point of change, and

(4) irregularly shaped structures can have a different shape factor input for each azimuthal sector.

The program is quite useful in performing "sensitivity analyses" of various construction characteristics. It has also been used extensively under OCD Subtask 3233B to determine the effects of decontamination (Reference 13).

This program was written in the GAT[4/] symbolic language for use on the Univac 1105 Computer located at the University of North Carolina, Chapel Hill, N. C. Due to input and output coding characteristics of the GAT language, the program is limited to handling 10 stories and 20 sectors per building.

It is recommended that this program, as fully described in Appendix D, be used for the computation of ground reduction factors in all key facilities.

II. PROGRAM DETAILS

A. Input

The required input data for the program are shown in Tabs 1 and 2 of Appendix D and a list of GAT variables used in the program is shown in Tab 3 of Appendix D. Data shown in Tab 1 are required for each building and data of the type shown in Tab 2 are required for each sector in the building. Each sector is reported almost independently of the other sectors with the only common data being floor and ceiling weights and heights of the detector story, story above, and story below.

All data are reported for a specific detector location on the first story (the same relative location is computed on all other stories). Frequently, an offeenter location is needed to evaluate various operations in a fallout environment.

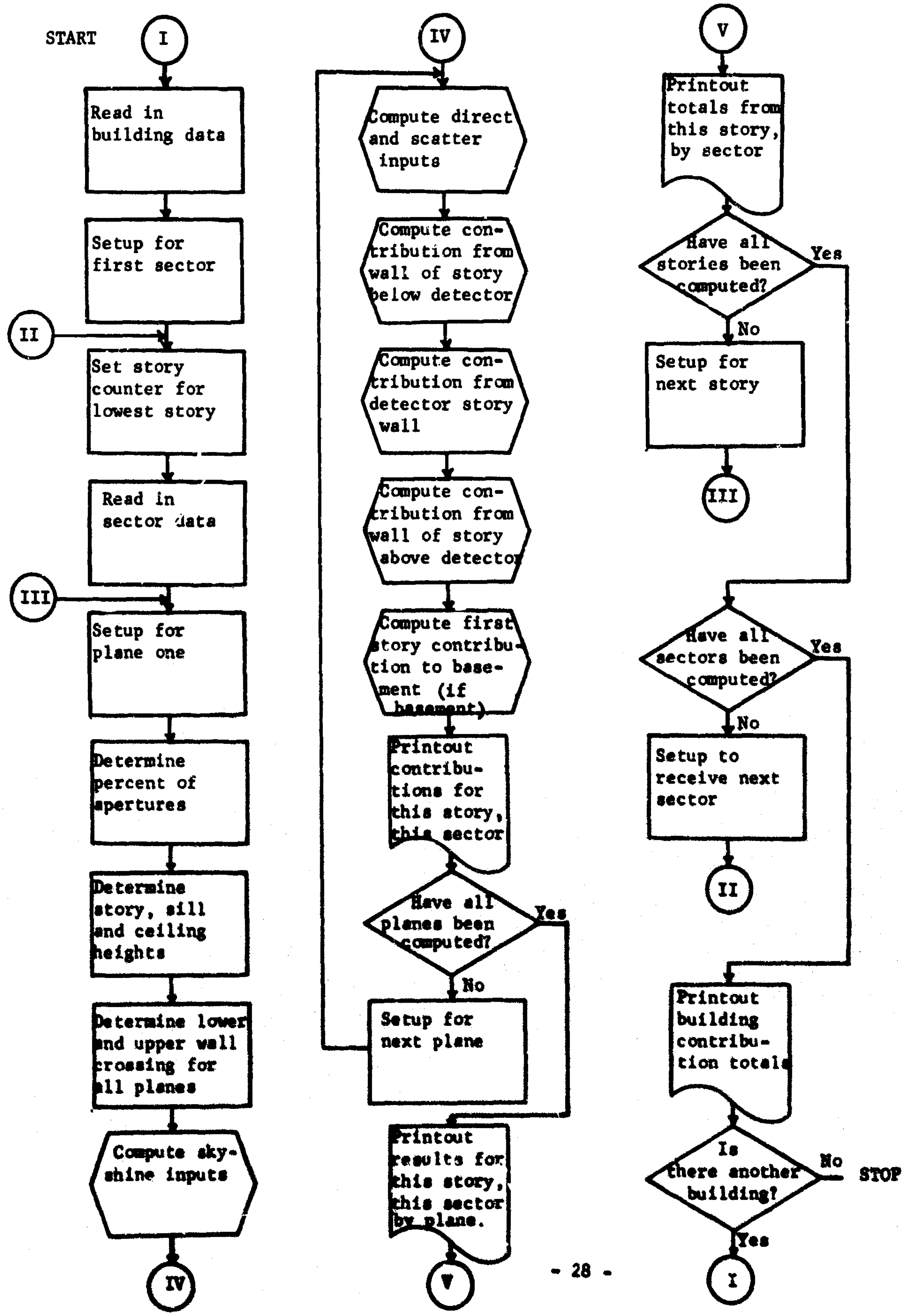
B. Computational Procedures

A generalized flow chart of the program operation is shown in Figure 4 and detailed flow charts are contained in Tab 4 of Appendix D. Basically the program consists of five major parts: (1) basic setup of data for each sector on each story, (2) computation of the contribution coming through the

4/ GAT is Univac's "Generalized Algebraic Translator" symbolic language.

FIGURE 4

Flow Chart of Computer Program for Key Facilities



wall of the detector story, (3) computation of the contribution from the story directly above the detector story, (4) computation of the contribution entering from the story directly below the detector story, and (5) computation of the contribution coming from the first-story wall to a basement shelter. The various wall contributions have within them routines to compute the skyshine, scatter, and direct contributions from the contaminated planes.

Functional equations, using symbols of Reference 1 , for the above computations are:

1. Detector Story

   a. Direct Contribution with Sill at or Above Detector Level

$$\frac{A_z}{360} B_w(X_e,H_4) B_w(X_i,3') G_d(\omega_{\ell d},H_4) [1-S_w (X_e)]$$

   b. Direct Contribution Through Apertures

$$\frac{A'_{za}}{360} B_w(X_i,3') G_d(\omega_{\ell a},H_4) B_w(X_e = 0,H_4)$$

$$- \frac{A'_{za}}{360} G_d(\omega_{\ell a}, H_4) B_w(X_i,3') [1-S_w(X_e)] B_w (X_e, H_4)$$

   c. Scatter Contribution

$$\frac{A_z}{360} B_w(X_e, H_4) B_w(X_i, 3') \frac{B_{ws} (\omega_s,X_e)}{B_w (X_e, H_4)} [G_s (\omega_\ell) + G_s(\omega_u)] S_w(X_e) E(e)$$

$$- \frac{A_{za}}{360} B_w(X_i,3') B_{ws}(\omega_s,X_e) G_s(\omega_a) S_w(X_e) E(e)$$

   d. Skyshine Contribution

$$\frac{A_z}{360} B_w(X_e,H_4) B_w(X_i, 3') [1-S_w(X_e)] [G_a(\omega_u) - P_{za}G_a (\omega_a)]$$

$$+ \frac{A_{za}}{360} B_w(X_i, 3') G_a(\omega_a) B_w(X_e = 0,H_4)$$

2. Story Above

$$\frac{A_z}{360} \; B_w(X_i, 3') \; B'_o\,(X'_o) \left\{ B_{ws}\,(\omega_s, X_e)[G_s\,(\omega'_u) - G_s(\omega_u)] \; S_w(X_e) \; E(e)[1-A_{ps}] \right.$$

$$+ B_w(X_e, H_u)\;[G_a(\omega'_u) - G_a(\omega_u)]\;[1-S_w(X_e)]\;[1-A_{ps}] + B_w(X_e = 0, H_4)\;A_{ps}\,\bullet$$

$$\left. [G_a(\omega_u) - G_a(\omega_u)] \right\}$$

3. Story Below

$$\frac{A_z}{360} \; B_w(X_i, 3') \; B_o(X_f) \left\{ B_w(X_e, H_\ell)[G_d(\omega'_{\ell d}, H_u) - G_d(\omega_{\ell d}, H_u)]\;[1-S_w(X_e)][1-A_{pd}] \right.$$

$$+ \; B_{ws}(\omega_s, X_e)\;[G_s(\omega'_\ell) - G_s(\omega_\ell)]\;S_w(X_e)\;E(e)\;[1-A_{ps}]$$

$$\left. + \; [G_d(\omega'_{\ell d}, H_4) - G_d(\omega_{\ell d}, H_4)]\;B_w(X_e = 0, H_4)\;A_{pd} \right\}$$

4. First Story Contribution to Basement

$$\frac{A_z}{360} \; B_w(X_i, 3') \; B'_o(X'_o) \left\{ [1-S_w(X_e)] \;\; B_w(X_e, H_u) \;\; [G_a(\omega'_u) - G_a(\omega_u)] \right.$$

$$- P_{za}[G_a(\omega'_{ua}) - G_a(\omega_{ua})] \; + P_{za}\;[G_a(\omega_{ua})] + B_{ws}\;(\omega_s, X_e)\;S_w(X_e)\;E(e)\,\bullet$$

$$\left. \Big[[G_s(\omega'_u) - G_s(\omega_u)] - P_{za}[G_z(\omega'_{ua}) - G_s(\omega_{ua})] \Big] \right\}$$

Symbols not defined in Reference 1 are:

A_z = Degrees in sector

A_{za} = Degrees of aperture in sector for scatter

A'_{za} = Degrees of aperture in sector for direct

A_{pa} = Fraction of aperture for skyshine

A_{pd} = Fraction of aperture for direct

A_{ps} = Fraction of aperture for scatter

P_{za} = Perimeter ratio of apertures in sector

ω_a = Solid angle fraction to top of window or detector story

ω_ℓ = Solid angle fraction to floor of detector story

ω_{ℓ}' = Solid angle fraction to floor of story below

$\omega_{\ell a}$ = Solid angle fraction down to lower sill

$\omega_{\ell d}$ = Solid angle fraction down to direct inner wall crossing on detector story

$\omega_{\ell d}'$ = Solid angle fraction down to direct inner wall crossing on story below

ω_{u} = Solid angle fraction up to ceiling of detector story

ω_{u}' = Solid angle fraction up to ceiling of story above

ω_{ua} = Solid angle fraction up to lower sill in story above

ω_{ua}' = Solid angle fraction up to top of aperture in story above

ω_{s} = One half of the solid angle fraction from the midwall to a plane composed of the source plane and its wall reflected mirror image.

NOTE: Both G_d and B_{ws} look-ups may be differenced values if there are limited planes of contamination or mutual shields.

C. Output Data

A sample output form is shown in Tab 5 of Appendix D and a description of the variables used in the output form is in Tab 6. The following output is given for each detector location in a building:

(1) Contribution from each plane of each azimuthal sector for the detector story, the story above the detector story, and the story below the detector story (contributing stories).

(2) Total contribution from each sector for each contributing story.

(3) Total contribution from all sectors for each contributing story.

(4) Total contribution from all contributing stories.

Much of the output is not necessary for analyzing key facilities; however, it is useful in other applications such as decontamination.

III. COMPARISON WITH HAND CALCULATIONS

Although the program uses close spacing in its tables, it does not interpolate between values (selects midvalues) and therefore a slight difference between hand and computer results may occur due to table look-ups. The computer program results have been within five percent of the value obtained by Engineering Manual hand calculations in twenty comparisons.

Chapter 4

Categorization of NFSS Phase 2 Data

I. INTRODUCTION

Categorization of structural characteristics of NFSS buildings is of interest to determine the correlation between structural data and protection from fallout radiation afforded by shelter areas[5/] and building parts. Information on the frequency of occurence of structural characteristics is also very important in the design of PF computer programs. Under OCD Subtask 1115A (Reference 2), RTI made a statistical study of building characteristics which were reported in the NFSS Phase 1. The following analysis of areaways, aperture sill heights, and interior partitions, which were reported in the NFSS Phase 2 on a data collection form as shown in Appendix E, completes the analysis of NFSS structural data. Should additional analyses be desirable, these data will be maintained in file.

II. SAMPLE CHARACTERISTICS

The sample of Phase 1 data which was categorized in Subtask 1115A contained 1541 buildings. Only 844 buildings of this parent sample were surveyed in Phase 2 and are included in the sample of Phase 2 data to be categorized. Phase 2 instructions state that all shelter areas surveyed in Phase 1 must be at least PF Category 2 for additional analysis in Phase 2. Therefore, 483 of the 1541 buildings in the Phase 1 sample were eliminated in the Phase 2 sample because they contained only PF Category 1 shelter areas. Also, Phase 2 data were not reported for 214 other buildings in the sample for one of the following reasons:

1. Permission to survey the building in Phase 2 was not given by the building owner.

5/ It is important to note that shelter areas are stories containing shelter in a building or building part. Thus, a "shelter area," as used in this chapter is not necessarily the whole of the NFSS shelter in a single story of a building.

2. The building had been destroyed since the Phase 1 survey.

3. Analysis or cost estimates were not made for shielding improvements to PF Category 2-3 shelters above the first story, hence these shelter areas were not included in Phase 2 data.

General characteristics of the Phase 1 and Phase 2 data used in categorization and characteristics of their parent population are listed in Table II. It is expected that the tabulations of the Phase 1 structural characteristics for the sample of 844 Phase 2 buildings would differ slightly from those for the sample of 1541 buildings. Such a comparative analysis has not been made.

III. DATA ANALYSIS

A. General

The Phase 2 data categorized in this report contained 844 buildings and 1167 building parts. In these building parts, there were 1030 basement shelter areas (story in a building or building part), 262 first-story shelter areas, and 838 upper-story shelter areas, giving a total of 2130 shelter areas reported. The distribution of these shelter areas by PF category is shown in Table III. Of the 1167 building parts, 88 percent (1030) contain basement shelter areas which account for 48 percent of the total shelter areas in PF Categories 2 through 8. The Phase 1 data indicated that 81 percent of the building parts contained basement shelter areas. The increased percentage of basement shelter areas in Phase 2 is expected because of the number of Phase 1 upper-story shelter areas in PF Category 1 which were not further evaluated in Phase 2.

Details of the categorization of Phase 2 data are presented in tabular and graphical form in Appendix F.

B. Areaways

There were 493 areaways reported for the 844 buildings categorized. Of the 1167 building parts reported, 337 have one or more areaways. A total of

TABLE II

Phases 1 and 2 Categorization Sample Characteristics

1. Total number of shelter areas (Total NFSS Phase 1) = 1,042,027
2. Total number of buildings (Total NFSS Phase 1) = 308,130
3. Total number of buildings rejected (Building containing no shelter areas rated in PF Category 1 or higher were rejected) = 73,646
4. Total number of buildings in the Phase 1 sample = 1541
5. Total number of buildings in the Phase 2 sample = 844
6. Total number of building parts in the Phase 1 sample = 2091
7. Total number of building parts in the Phase 2 sample = 1167
8. Total number of shelter areas (PF Categories 1 through 8) in the Phase 1 sample = 4421
9. Total number of shelter areas (PF Categories 2 through 8) in the Phase 2 sample = 2130

TABLE III

Phase 2 Shelter Areas by PF Category

PF Category	2	3	4	5	6	7	8	Total
			Basement Shelter Areas					
Number	250	97	194	136	112	58	183	1030
Fraction	.2428	.0942	.1883	.1320	.1087	.0563	.1777	1.0000
			First Story Shelter Areas					
Number	97	29	66	30	22	7	11	262
Fraction	.3702	.1107	.2519	.1145	.0840	.0267	.0420	1.0000
			Upper Story Shelter Areas					
Number	218	91	248	130	95	30	26	838
Fraction	.2602	.1086	.2959	.1551	.1134	.0358	.0310	1.0000

109 of these building parts had areaways reported on more than one building side.

Table F-I of Appendix F shows the distribution of the 337 building parts containing areaways by PF category. Areaways occur most frequently in the lower PF categories; however, a significant number appear in all categories, with PF Category 8 having 37, or 11 percent of the total areaways.

Table F-II and Figure F-1 give the total areaways in all PF categories by width (from 2 to > 10 feet) and by percent of building side length (0 through 90 percent). These data indicate that 66 percent of the areaways are 30 percent or less of the building side length and that 83 percent are five feet or less wide. This information helps to justify the use of azimuthal sectors in a PF computer program rather than having to assume that the areaway runs the entire length of the building. If an areaway is left out of a computation, the PF is nonconservative; if it is considered to be the total length of the building, the PF is too conservative.

Tables F-III through F-IX and Figure F-2 through F-8 show the number of areaways in each PF category by width and length. There is no marked difference in the number of areaways reported by PF category; PF Category 8 has as many or more than PF Categories 3, 6, and 7 and almost as many as PF Category 5. The data for each PF category are like that for total areaways in that the majority of areaways in each category are 30 percent or less of the building side length and are five feet wide or less.

These data regarding the occurrence and size of areaways are especially important when it is understood that the presence of an areaway can change the PF of a shelter by at least one category. For example, the ground contribution in a 90 foot x 110 foot unexposed basement with 70 psf exterior walls increases

by 90 percent when an areaway 5 feet wide by 55 feet long (with 15 percent apertures) is added adjacent to the long side of the basement.

C. Aperture Sill Heights

Table F-X gives the total basement, first-story, and upper-story shelter areas with aperture sill heights reported by PF category. Sill heights were reported for only 625 of the 1030 basement shelter areas categorized; however, it is more interesting to note that 56 of the 262 first-story shelter areas and 19 of the 838 upper-story shelter areas had no sill heights reported, thereby indicating no apertures for these 75 shelter areas. This would cause the shelter area to have higher PF's, but it also means that these areas would require additional ventilation to be eligible for marking at 10 square feet per shelter space.

Sill heights reported in the basements, first, and upper stories are given in Tables F-XI through F-XIII and in Figures F-9 through F-11. In basements, the vast majority of the sill heights are from 3 to 6 feet for each PF category, with the mode being 5 feet. Seventy-five percent of the sill heights are reported in PF Category 5 or less shelters. For first stories, 80 percent of all sill heights are from 2 to 4 feet and 89 percent of all shelters with sill heights reported are in PF Category 5 or less. In upper stories, 90 percent of the sills are from 2 to 3 feet high and none are higher than 5 feet. The most significant conclusion one can draw from these data is the clustering of sill heights around a 3-foot high detector location. This requires that computer programs must be able to determine the direct radiation penetrating the one foot of aperture when a 2-foot sill is reported. NFSS Phase 1 calculations assumed sill heights to be zero; Phase 2 adjustments were based on zero or 3 feet, with no intervening heights.

D. Interior Partitions

1. Parallel Partitions

The total numbers of basement, first-story, and upper-story shelter areas with parallel partitions reported are presented in Table F-XIV by PF category. Parallel partitions were reported for 525 of the 1030 basement shelter areas (51 percent), 178 of the 262 first-story shelter areas (68 percent), and 656 of the 838 upper-story shelter areas (78 percent). In the Phase 1 categorization sample, only 17 percent of all shelter areas had interior partitions reported because only load bearing or fire break partitions were reported.

In order to categorize these parallel partition data by shelter areas, it was necessary to determine an average partition psf for each shelter area. Therefore, the average partition psf reported for each of the four sides was multiplied by the number of parallel partitions reported for that side; these four products were added and then divided by four in order to get the average psf for each shelter area. These parallel partition data are reported in Tables F-XV through F-XVII and Figures F-12 through F-14 of Appendix F for basement, first, and upper stories by PF category and average psf per shelter area.

The number of parallel partitions (in each psf) reported in basements surprisingly are evenly distributed by PF category and they have a median of 25 psf. It is also important to note that 19 percent of the partitions are an average of 60 psf or greater.

In first stories, the psf of parallel partitions is quite variable with a median of 30 psf. PF Category 2 contains 34 percent of the partitions and PF Category 4 contains 28 percent.

In upper stories, the median is 25 psf. PF Category 2 accounts for 23 percent of the partitions and PF Category 4 has about 32 percent. Partitions of 30 psf or greater are reported in 65 of the 218 PF Category 2 shelters. The barrier factor for 30 psf is approximately 0.5; therefore, the Phase 1 PF must have been no more than 35 or the principal contribution in these shelters must have come from the roof. Otherwise, these shelters would have been placed in PF Category 3 (e.g., maximum reduction factor of .025 for PF Category 2 x 0.5 = .0125, which is within PF Category 3). This point emphasizes the need for PF computer programs to account for partition location in order that partitions may be used in calculating roof contribution. Four shelters were reported with an average of at least 100 psf partitions and yet remained in PF Category 2.

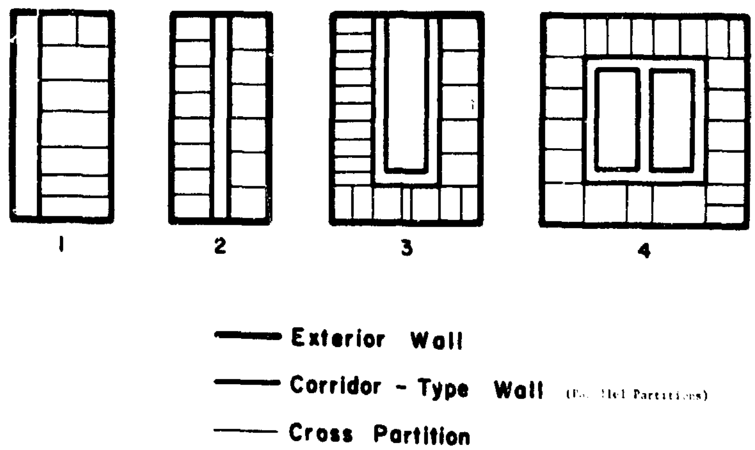
2. Cross Partitions

Cross partitions are those partitions separating adjacent rooms, as shown in Figure 5. The numbers of each type of cross partition reported are shown in Table F-XVIII and a breakdown by shelter area and PF category is given in Table F-XIX. Cross partitions were reported for 761 of the 2130 shelter areas categorized. Of these cross partitions, there were 245 reported for basement shelter areas, 98 for first-story shelter areas, and 418 for upper-story shelter areas, which is 24, 37, and 50 percent, respectively, for the total basement, first and upper-story shelter areas.

FIGURE 5

Code Number For Building Type

(Column 69 of Phase 2 DCF)



The cross partition data were categorized separately for each type of cross partition (Types 1 through 4 of Figure 5) by PF category and psf for basements, first, and upper stories and reported in Tables F-XX through F-XXII and Figures F-15 through F-26 of Appendix F.

For basement shelter areas, 89 percent of the cross partitions reported are Type 1 or Type 2. The numbers of basement shelter areas with cross partitions reported are fairly evenly distributed by PF category. The median psf for all types of cross partitions in basements is 40 psf.

In first-story shelter areas, 60 percent of the partitions are Type 2, 42 percent of which are in PF Category 2. The median is 40 psf.

Finally, for upper stories, 72 percent of the partitions are Type 2 (42%) or Type 4 (30%) with 18 percent in Type 1. Very few partitions of any type are reported above PF Category 5 or 40 psf. Of the 761 shelter areas with cross partitions reported, only 9 percent are Type 3 partitions.

Chapter 5

Area Factors

I. INTRODUCTION

The protection factor (PF) computational procedure (Reference 14) of the National Fallout Shelter Survey (NFSS) used predetermined area factors to estimate fractions of total floor areas offering protection greater than a predetermined value. The area factors used in the NFSS are shown in Table IV.

TABLE IV

NFSS Phase 1 Area Factors

PF Category	PF Range	Area Factor
6 - 8	250 - over 1000	1.0
5	150 - 249	0.7
4	100 - 149	0.3
2 - 3	40 - 99	0.5

For shelters in PF Category 4-8 (PF 100 to >1000), area factors represent the fraction of the total floor area which does not drop below PF 100. For shelters with a center PF within PF Category 2-3 (PF 40 to 99), area factors represent fractions of shelter areas with a perimeter PF of approximately 70 percent of the shelter (S-AREA) center PF.

This chapter presents analyses of the effects of building characteristics and combinations of ground and roof contributions on the usable shelter area of a building.

II. LIMITATIONS OF NFSS AREA FACTORS

The NFSS Computer Program area factors represent usable areas in the first story of a windowless square building receiving only ground contribution. A previous evaluation of area factors (Reference 2) for this type of structure indicated that the area factors presented in Table IV are significantly conservative (from .1 to .2 should be added to each area factor) to bring them to agreement with results of the Engineering Manual procedure (Reference 1).

For the intended objective of determining gross estimates of the total number of available shelter spaces by machine methods, the area factor approach is excellent. However, a careful analysis of each building in question should be made before final determination of the actual area of the shelter is made. Relevant considerations are:

(1) Center PF - All applications of NFSS area factors are based on the PF at the center of a building. This means that if the center PF is not in PF Categories 2 through 8, no area factor is applied and the entire story is considered to have a PF less than the center PF. In reality, this assumption may be wrong. Because of mutual shielding, irregularly spaced interior partitions, grade level, etc., the PF might be higher at the end of a building story than at the center.

(2) Interior Partitions - If a building contains interior partitions, the PF may drop rapidly outside the area bounded by partitions. In Phase 1 of the NFSS the location of partitions was not given unless a core was reported. A core is defined in Reference 15 as "a central portion

of a story surrounded on two or more sides by interior partitions of heavy construction." Cores were reported in Phase 1 for only the first and second stories of a building and data collection forms allowed only one partition per building side to be noted.

The area factor for a building with a core area or any interior partitions may be quite different from one for a building with no partitions. For example, if the area bounded by partitions in a story with a center PF in Category 4 is greater than .3 (Category 4 area factor) of the total floor area, the area of the shelter very likely extends to the partitions rather than just .3 of the total area. Approximately 78 percent of Phase 2 upper story shelter areas have parallel partitions. This in itself is reason to believe that substantial increases in total shelter area might be gained through use of a PF computational procedure that would consider the location of interior partitions and compute PF's at points other than the center of the building.

(3) Floor Thickness - The majority of buildings in the NFSS and all those surveyed by RTI are exposed to limited planes of contamination. A statistical study of Phase 1 data (Reference 2) indicated the modal width of all planes of contamination contributing to a shelter story to be less than 60 feet for every PF category. Because of these narrow planes of contamination, the thickness of floors for stories above grade is an important parameter to consider when determining the total area of the shelter. Due to the narrow planes of contamination, ground contribution to stories above grade often must penetrate the floor

below the detector. The PF is therefore quite dependent on the mass thickness of the floor through which the radiation must penetrate. For example, for a plane less than 300 feet wide, Technical Operations Research determined that the dose rate at an upper story corner position in a windowless building with light floors (X_f = 20 psf) was 1.4 times that at the center position whereas it was 2.5 times greater than that at the center for thick floors (X_f = 80 psf) (See Table 42 of Reference 16).

(4) Apertures - Analyses of aperture contributions in a square building indicated that the usable area of a shelter depends on the percentage of apertures (Reference 2). For example, on the second floor of a 5000 square foot hypothetical building with a center PF of 125, the fraction of the area having a protection factor greater than 100 is 0.43 with no apertures and increases to 0.56 with 10 percent apertures. When apertures were added, the wall mass thickness was increased to maintain a center PF of 125.

(5) Roof Contribution - In shelters where the predominant contribution comes from ground sources surrounding the building, the center of an above-ground shelter should be the point with the highest PF. The PF would decrease closer to the exterior wall. However, when roof or ceiling contribution is also present, the shelter area may be quite different in size and location from that with no such contribution. For example, with the predominant contribution coming from the roof, the safest area would be closest to the exterior wall and the PF would decrease as the center is approached. Upper stories of high rise buildings, as well as basements, are shelter areas where roof contribution can often exceed ground contribution.

III. RTI INVESTIGATIONS

A. Method of Approach

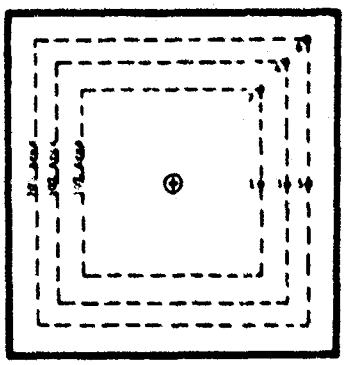
Using Engineering Manual and AE Guide (References 1 and 17) procedures, numerous computations were made to determine the range of PF's in various size buildings subject to combinations of roof and ground contributions. After the exterior wall mass thickness giving a desired center PF in a building was determined, computations were made for 6 other points in the building as illustrated in Figure 6.

Points 1 and 2, 3 and 4, and 5 and 6 are on the perimeter of areas arbitrarily chosen to be 30, 50, and 70 percent, respectively, of the total building area. These points are located at approximately 54.8, 70.7, and 83.7 percent of the distance from the center perpendicular to the exterior wall and from the center to the corner.

Roof contributions were determined by the Engineering Manual Method; ground contributions calculated by the AE Guide which assumed all buildings to be square. Calculations were made for buildings with the characteristics given in Appendix G.

FIGURE 6

Detector Locations for Area Factor Computations



B. Findings

1. Roof Contribution Only

Using the same structural data required to give a desired PF in the center of a square building, Engineering Manual roof computations were made for the 6 points shown in Figure 6. These data were then plotted as illustrated in Figure 7 in order to determine by interpolation the boundaries of the area with a selected PF. The illustration shows the distances from the center of a 10,000 square foot building to points where the PF reaches 100 on a line perpendicular to the exterior wall (line through points 1, 3, and 5 of Figure 6) and on a diagonal line (points 2, 4, and 6).

These points determine the boundaries of the area having a PF of at least 100 within a building story and it was thus possible to calculate the area of the shelter. For the case of all-roof contribution, the shelter is adjacent to the exterior walls and not in the center of the building. Very little variation was noted in the usable shelter, expressed as a percent of the total area, for buildings in the 2,500 to 10,000 square foot range.

Conservative area factors for buildings with all roof contribution are given in Table V. These area factors may also be used for rectangularly shaped buildings when the AE Guide procedure, which does not consider the building shape, is used. This is because a rectangular building with the same area and construction characteristics as a square building will have less roof contribution.

FIGURE 7

Variation of PF with Detector Location - All Roof Contribution

(10,000 Square Foot Building - Center PF of 85)

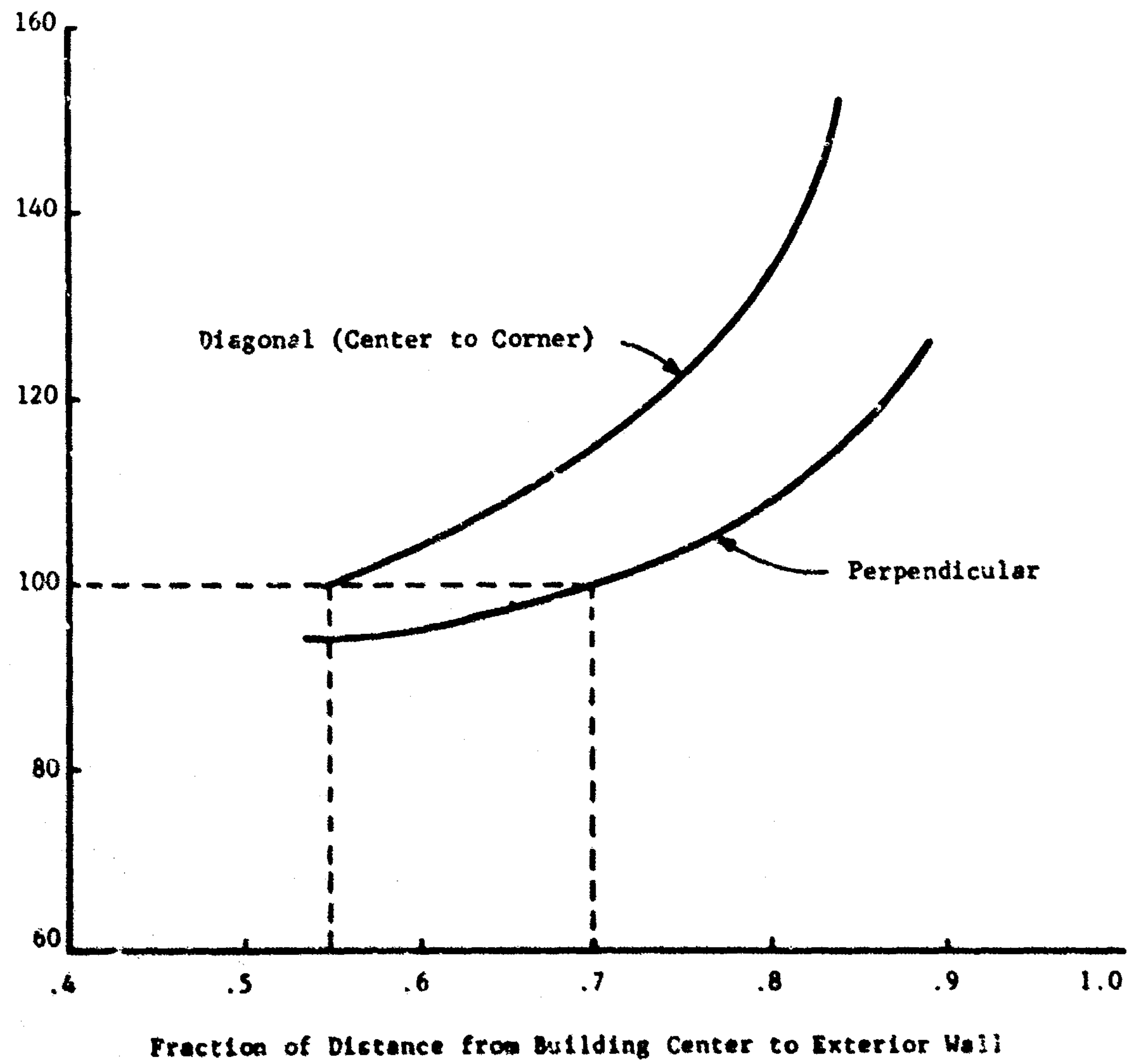


TABLE V

Area Factors - Roof Contribution Only

	PF Category	Area Factor
Area Greater Than PF 100	4 - 8	1.00
	3	.56
	2	.18
Area Greater Than PF 40	2 - 8	1.00
	1	.26

It is important to note that shelter areas with a center PF less than 40 and receiving predominantly roof contribution still have considerable area of PF 40 or better.

(2) Ground and Roof Contribution

Most stories of structures receive some combination of ground and roof contribution. Therefore, area factors for this type of structure are very important in determining the shelter area of a story.

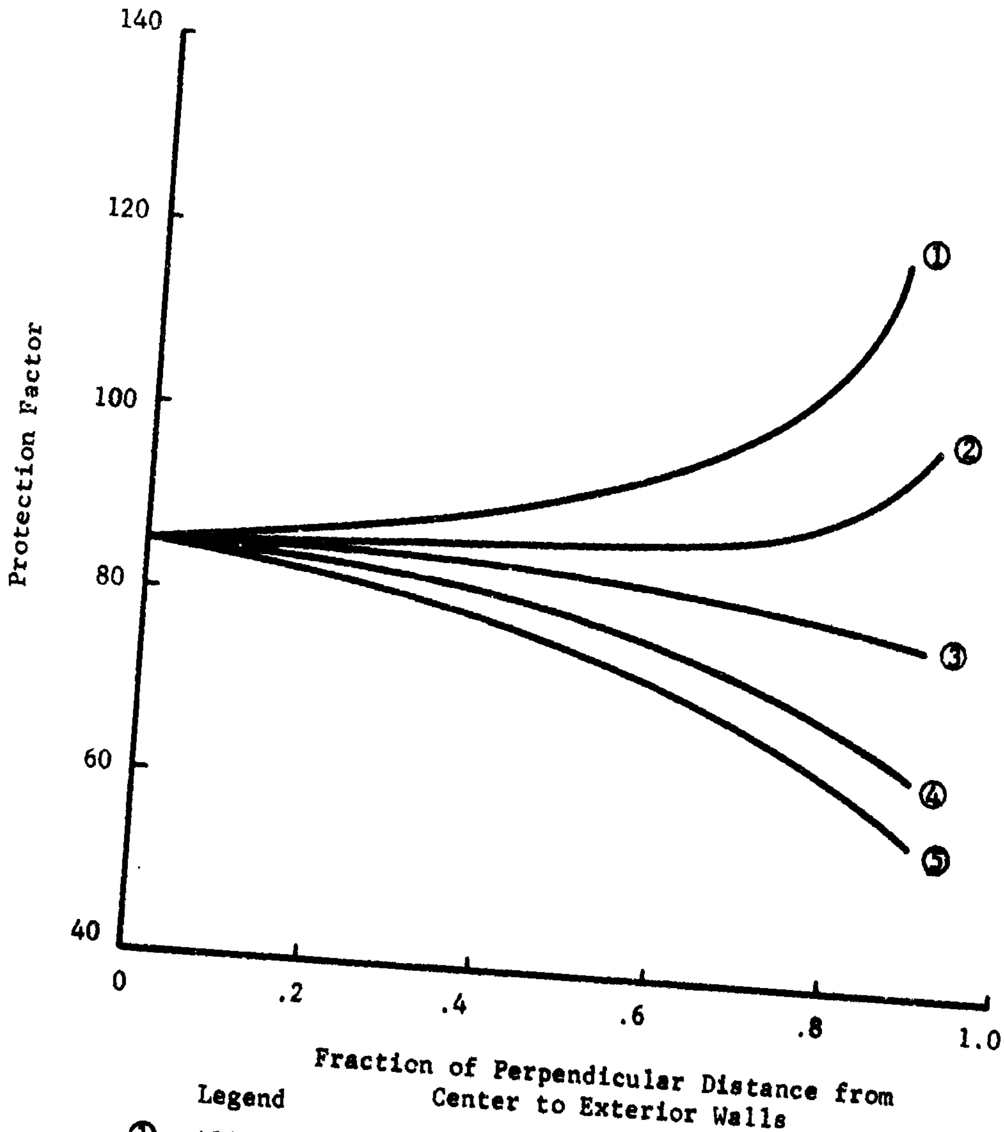
Various combinations of ground and roof contributions, ranging from all-ground to all-roof, were calculated for upper stories of the hypothetical buildings described in Appendix G. The contributions for each building size and center PF were plotted as shown in Figure 8 . This figure illustrates the variations in PF on a line from the center perpendicular to the exterior wall in a 10,000 square foot area with a center PF of 85. Similar graphs were prepared for PF's on a line from the center of the building to the corner of the building. The boundaries of shelter area within a given PF range were then determined from these charts.

As was found for all-roof contribution, the shelter areas were fairly insensitive to changes in total building area. Therefore, conservative shelter area data were again used and are presented in

FIGURE 8

Variation of PF with Detector Location and Combinations of Roof and Ground Contributions

(10,000 Square Foot Building - Center PF of 85)



Legend

1 All Roof
2 3/4 Roof - 1/4 Ground
3 1/2 Roof - 1/2 Ground
4 3/4 Roof - 1/4 Ground
5 All Ground

FIGURE 9

Area Factors for Combinations of Ground and Roof Contributions

(Shelter Areas with PF Greater than 100)

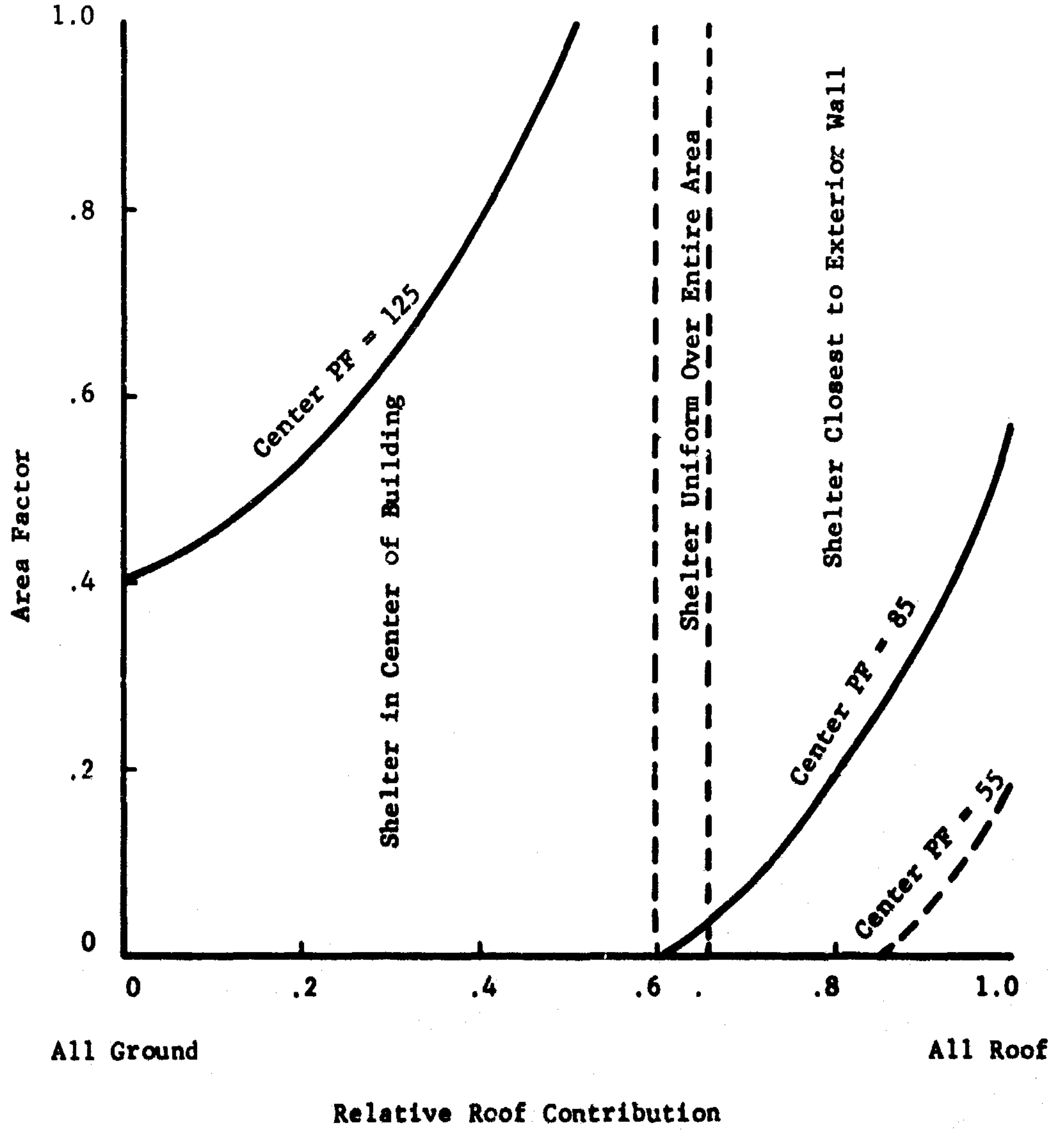


Figure 9 to show the area of a story with a PF of 100 or better when exposed to infinite planes of contamination. This figure shows the area factors for any combination of ground and roof contribution when the center PF is known. This is therefore a very valuable figure for use with a simplified procedure such as the AE Guide.

IV. RECOMMENDATIONS

For hand computational procedures where only a center PF is generally calculated, it is recommended that Figure 9 be used to determine the area with a PF of 100 or more.[6/]

Due to the complexities of the combined effects of apertures, interior partitions, floor thickness, etc., the area of shelter in buildings of similar size with the same center PF can be quite different. The PF computational procedure which has been programmed by RTI under Contract No. OCD-PS-64-65 for use on a Control Data Corporation CDC 3600 Computer, therefore, does not use predetermined area factors. The PF is machine calculated at the center and at 8 predetermined offcenter detector locations, which allows the computer to determine the approximate areas of a building having a PF of a predetermined value.

6/ In a related study, a simple technique for determining shelter boundaries in a building by making only one PF calculation in the shelter area was developed and reported in Reference 3 . The technique accounts for nonuniform ground contribution as well as the characteristics discussed in this chapter.

Chapter 6

The Effect of Ingress of Fallout Through Apertures

I. INTRODUCTION

In a thermonuclear attack, damage to many fallout shelters will be limited to broken windows. This study was made to determine the effect of ingress of fallout particles through open windows on the protection factor (PF) of a shelter. PF's of several hypothetical buildings without ingress (referred to as "initial PF") were calculated using the RTI computer program for the CDC 3600 (Reference 18), which is based on the Engineering Manual Method (Reference 1). The contribution of ingress fallout through open windows was then calculated manually using the Engineering Manual Method. The resultant PF is referred to as "effective PF." The PF's with and without varying amounts of ingress fallout were then compared.

II. INGRESS COMPUTATION

A. Building Parameters

Small and large hypothetical buildings with floor areas of 2,000 square feet (25 x 80) and 10,000 square feet (80 x 125) were used in this investigation. The buildings were structures with five ten-foot high stories and with ten-foot basements that were 50 percent exposed. All building configurations had 100 psf exterior walls and roofs, and all sides were exposed to a contaminated ground plane 80 feet wide. All cases were examined with and without 40 psf interior partitions (located 10 feet in from the exterior walls) and with either 20 psf or 80 psf floor weights throughout. All stories, including the basement, were assumed to have ingress through either of two

aperture configurations. One configuration had 50 percent of the wall area in windows with 3-foot sill heights. The other case had one window, 5 feet wide by 4 feet high with a 3-foot sill, in the center of each wall.

Detectors were located in the third story and basement with both a center and offcenter location (on the center line half the distance from the center to the exterior wall) three feet above the floor. This range of structural characteristics was selected in order to determine the effect of ingress fallout in buildings of both light and heavy construction.

B. Ingress Fallout Distribution

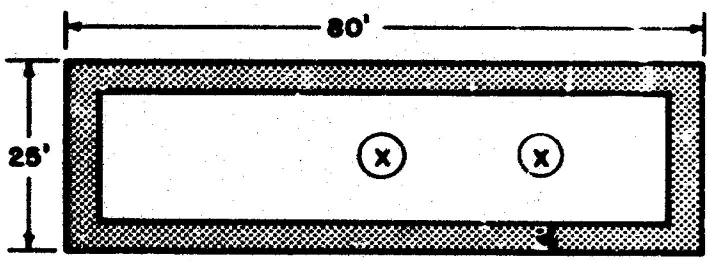
Data obtained by NRDL in the study of the Costa Rican volcano, Irazu (Reference 19), were considered when determining the deposition of fallout for this analysis. With natural ventilation, NRDL found that the areal mass density of ingress fallout just inside a window was about four percent of that outside the building. When a fan was used to pull air in the window, the density of the ingress fallout increased to approximately ten percent of the outside fallout. For this study of hypothetical buildings, ingress fallout densities of 2 percent and 20 percent were used in order to show the effect of an extreme range of fallout densities.

The buildings with 50 percent apertures were computed assuming a four-foot wide strip of ingress fallout around the inside perimeter of the exterior wall and also with the same total mass of fallout spread over the entire floor. When partitions were considered, the fallout was spread between the exterior wall and partition. For the buildings with one aperture per wall, it was assumed either that ingress fallout was concentrated in an area the same size as the window (5' x 4') and directly in front of it, or that this same amount was spread over the entire floor. These configurations were chosen to represent the range of ingress fallout distribution that might be expected. Floor plan views of the third story of the 2,000 square foot building are shown in Figure 10 as an illustration of these distributions.

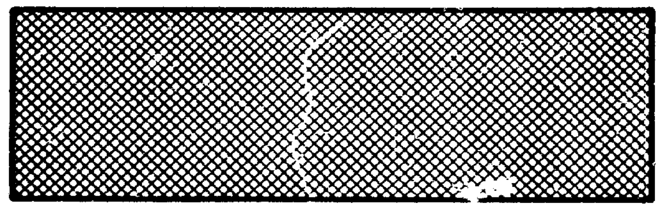
FIGURE 10

Plan Views of Building Showing Ingress Fallout Distribution
(Third Story of 2,000 Square Foot Building)

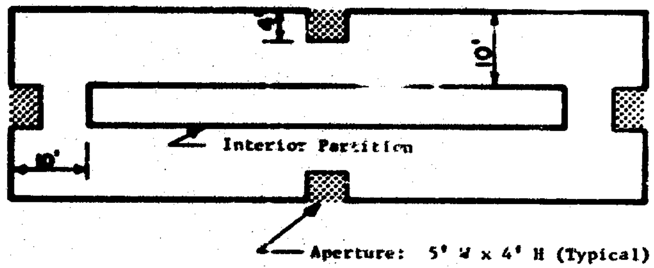
a. Ingress Fallout Located Just Inside 50 Percent Apertures
(With or Without Partitions)



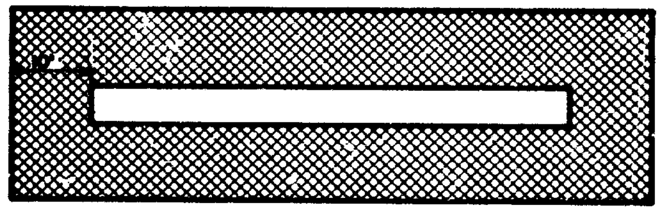
b. Ingress Fallout Distributed Over Entire Area - Without Partitions
(One Aperture or 50% Apertures)



c. Ingress Fallout Located Just Inside One Aperture Per Wall
(With or Without Partitions)



d. Ingress Fallout Distributed Over Entire Area - With Partitions
(One Aperture or 50% Apertures)



KEY

Ingress fallout concentrated at apertures.

Ingress fallout distributed over entire area or to interior partitions. Note: This is the same amount of fallout shown in Cases a. and c. distributed over a larger area.

(X) Detector location (typical for all buildings).

C. Ingress Computation Procedures

Contributions from ingress fallout were determined through the use of Engineering Manual Charts 1 (B_f) and 6. For the third-story detector location, contributions from the second, third, and fourth stories were determined. For basements, contributions from ingress fallout in both the exposed basement and the story above were determined.

Solid angle fractions for the strip around the inside perimeter of the exterior wall were determined through use of Engineering Manual Chart 3. The contribution from the strip was determined by differencing the Chart 6 values for these solid angle fractions.

Solid angle fractions (ω) for the radii from the detector to the inner and outer edges of the strip inside a single aperture were determined by the equation given in the Engineering Manual (Reference 1)

$$\omega = 1 - \cos\theta$$

where $\theta = \mathrm{Tan}^{-1} \frac{R}{Z}$,

R = Radius from detector to inner or outer edge of strip, and

Z = perpendicular distance from detector to plane of strip of contamination.

The Chart 6 contributions for these solid angle fractions were then differenced and multiplied by the fraction of the total ring area occupied by the 4' x 5' area of fallout.

III. FINDINGS AND CONCLUSIONS

The effect of ingress fallout on the PF's of the third story of the buildings are presented in Tables H-I through H-IV of Appendix H. The effects

on basement PF's are presented in Tables H-V through H-VIII of Appendix H. The change (decrease) in PF due to ingress fallout is shown in Figure 11 for the center of the third story of the 5-story, 2000 square-foot, building configurations. PF changes in the basements of the same structures are shown in Figure 12. The most significant changes in PF were in the 2000 square-foot building; therefore, the 10,000 square-foot data are not presented. These figures indicate significant changes in PF, but generally only for the 20 percent concentration of ingress and 50 percent aperture configurations, which are unexpected extremes of each parameter.

Figure 13 shows the cumulative distribution of the fractional decrease in PF due to ingress fallout for all 128 cases studied. A change in PF of 10 percent or less was noted in more than 70 percent of the 128 cases. A change of 25 percent or greater was noted in only approximately 10 percent of the cases.

Ohter conclusions derived from an analysis of Figures 11 through 13, Tables H-I through H-VIII,and supporting calculations are:

(1) As expected, ingress fallout was found to have less effect in the larger buildings.

(2) Ingress fallout has a greater effect on the higher initial PF's. Ingress fallout is especially significant in basements due to the higher initial PF's found in basement areas.

(3) The offcenter detector data were very similar to data for the center.

(4) Contributions from the stories above and below the detector story accounted for a maximum of 30 percent of the ingress contribution in buildings with 20 psf floors and less than 10 percent in buildings with 80 psf floors.

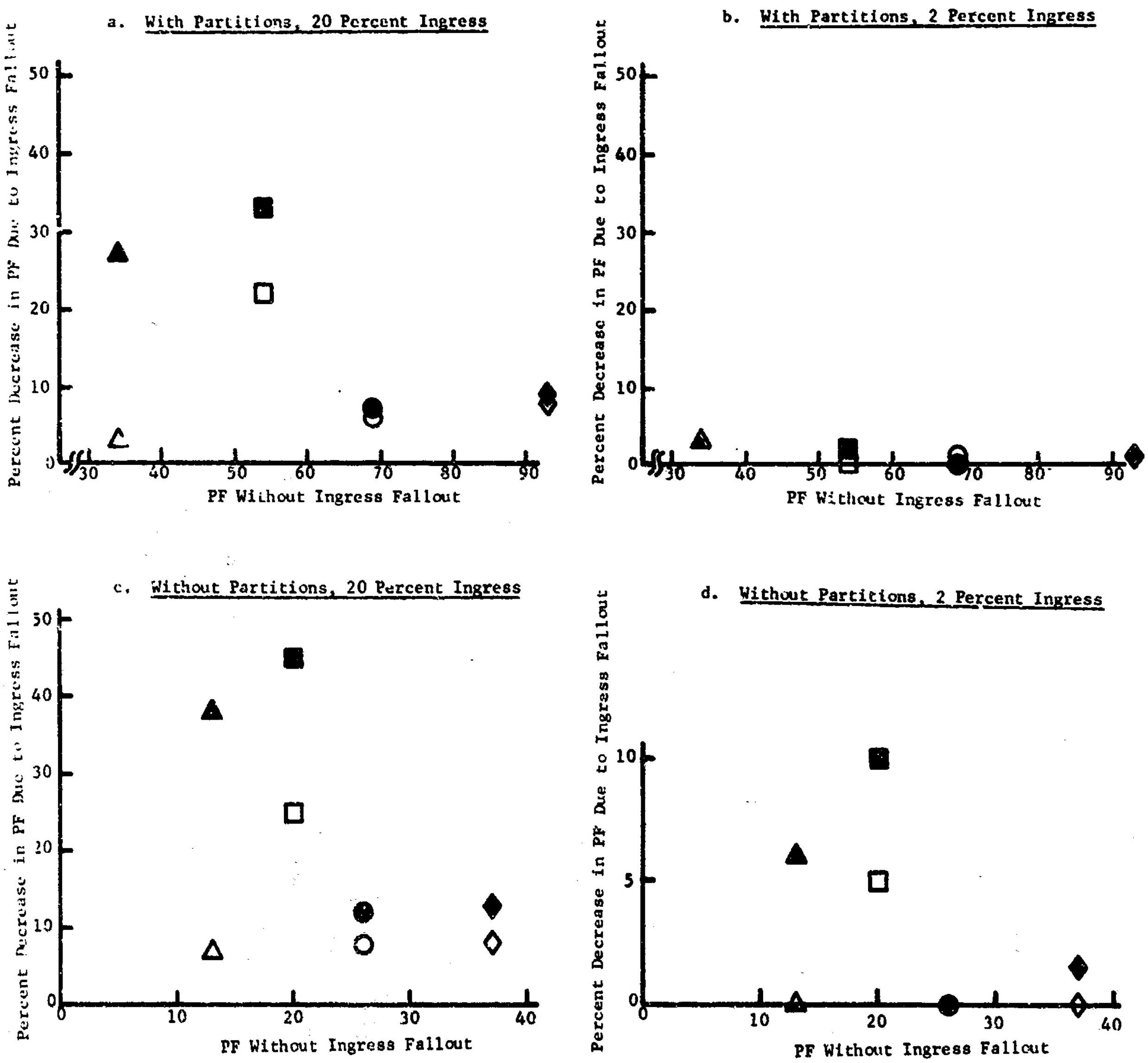
(5) For upper stories, ingress fallout equal to two percent of the outside concentration causes a maximum of 10 percent decrease in PF.

(6) The 20 percent concentration reduces the upper story PF by as much as 30 percent in a building with interior partitions and by approximately 50 percent without them.

(7) A maximum reduction of PF of approximately 55 percent is noted for basements in both building sizes.

FIGURE 11

Decrease in Center PF Due to Ingress Fallout - Third Stories
(2,000 Square Foot Buildings With and Without Partitions)



○ One aperture per wall, fallout distributed over perimeter, 20 psf floors.

● One aperture per wall, fallout distributed over entire floor, 20 psf floors.

△ 50% apertures, fallout distributed over perimeter, 20 psf floors.

▲ 50% apertures, fallout distributed over entire floor, 20 psf floors.

◇ One aperture per wall, fallout distributed over perimeter, 80 psf floors.

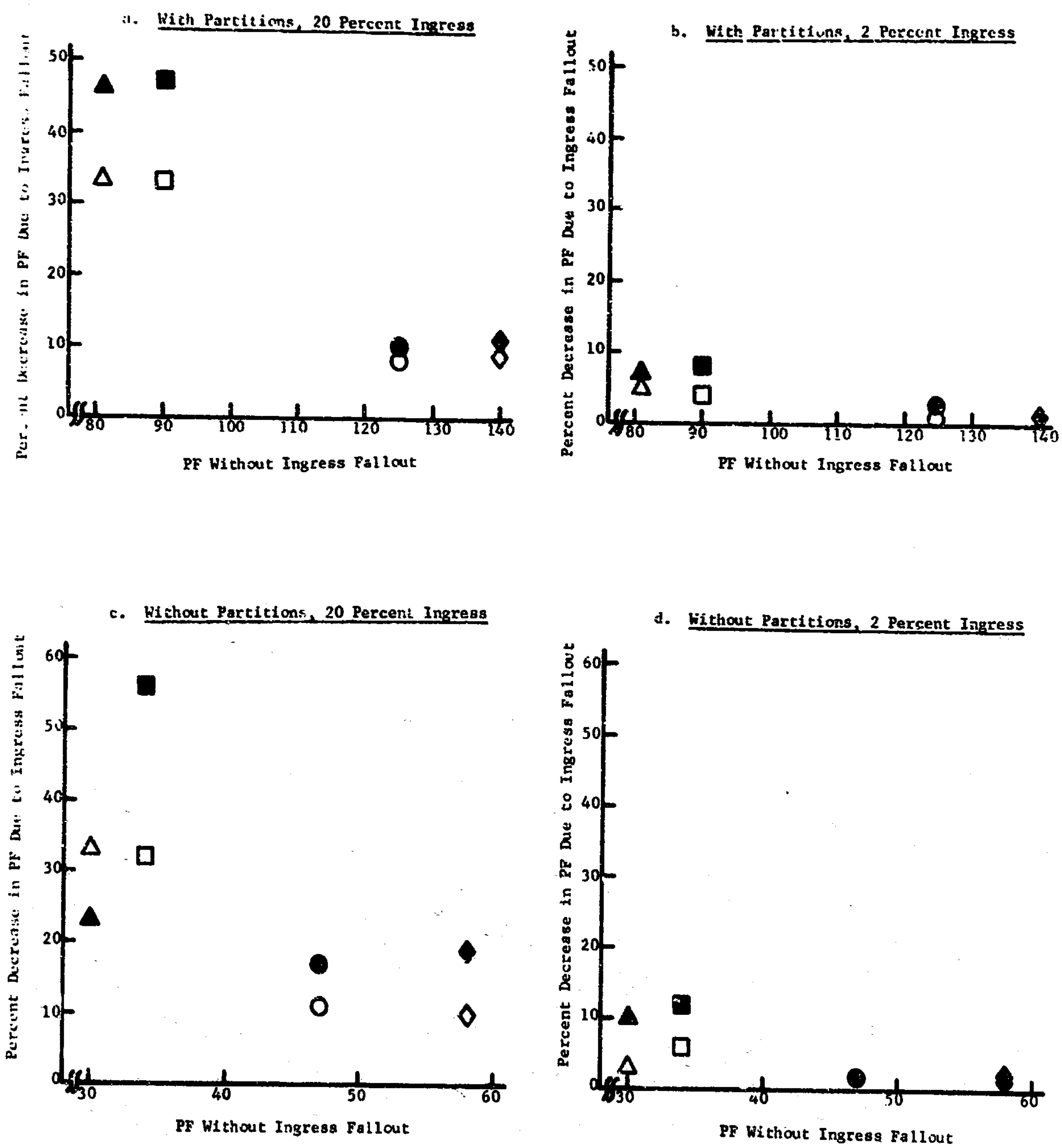
◆ One aperture per wall, fallout distributed over entire floor, 80 psf floors.

□ 50% apertures, fallout distributed over perimeter, 80 psf floors.

■ 50% apertures, fallout distributed over entire floor, 80 psf floors.

FIGURE 12

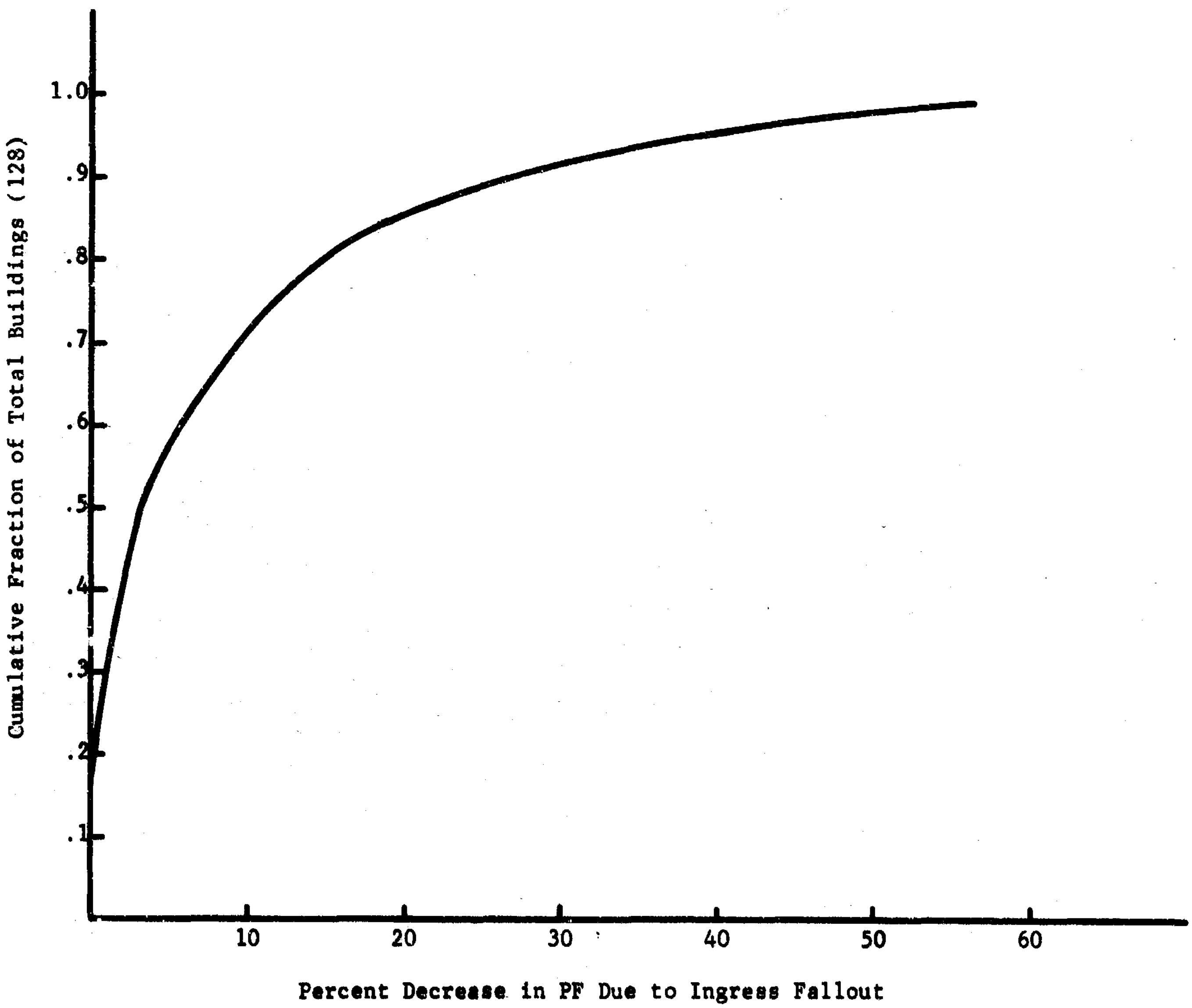
Decrease in Center PF Due to Ingress Fallout - Basements
(2,000 Square Foot Buildings With and Without Partitions)



○ One aperture per wall, fallout distributed over perimeter, 20 psf floors.
● One aperture per wall, fallout distributed over entire floor, 20 psf floors.
△ 50% apertures, fallout distributed over perimeter, 20 psf floors.
▲ 50% apertures, fallout distributed over entire floor, 20 psf floors.
◇ One aperture per wall, fallout distributed over perimeter, 80 psf floors.
◆ One aperture per wall, fallout distributed over entire floor, 80 psf floors.
□ 50% apertures, fallout distributed over perimeter, 80 psf floors.
■ 50% apertures, fallout distributed over entire floor, 90 psf floors.

FIGURE 13

<u>Cumulative Distribution of Buildings by</u>
<u>Decrease in PF Due to Ingress Fallout</u>
(128 Buildings)



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Appendix A

Contractual Scope of Work

The contractual description of Work Unit 1115B, Analysis of Survey Data, Part III (Cost and Protection Analysis of NFSS Structures), Contract Number OCD-PS-64-56 and Contract Number N-228-(62479)-66109, is as follows:

> "Analyze Phase 2 data from the NFSS to indicate relative importance of shielding characteristics in order to improve PF calculations and to indicate the most important modifications to improve PF. Utilize this data and studies of recurring types of key facilities under various geographic and construction conditions to identify the most critical engineering characteristics of the structure which would require modification for occupancy and operations in a fall-out situation. Provide PF computational procedures for special characteristics of those key facilities for the electronic computer program."

Appendix B

<u>Calculations for Shielding Afforded by Large Machinery</u>

I. INTRODUCTION

The purpose of this Appendix is to investigate the additional shielding that would be provided by massive items (bulk shield). Of primary interest will be the consideration of ducts or holes traversing part or all of a massive item. For instance, what is the shielding afforded by a generator or motor considering the cooling passages along the armature. Or, what is the effect of a draft tunnel through the base of a furnace on its shielding characteristics?

II. TECHNICAL DISCUSSION

We will first consider the effect of holes which go completely through a bulk shield. These holes (which will be approximated as cylinders) will provide a path for radiation streaming. A general configuration for the problem is shown in Figure B-1.

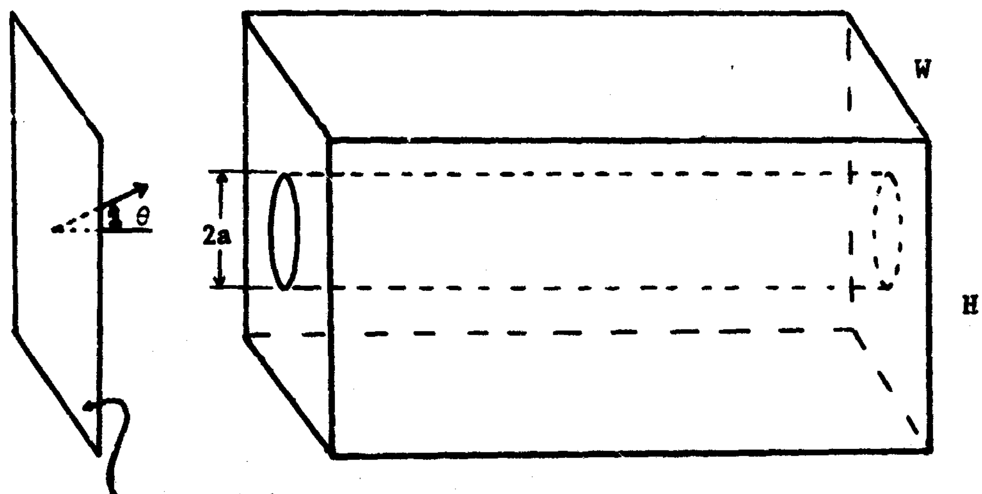
The flux from a source plane as indicated in Figure B-1, which may be an exterior wall of a building, is assumed to have an obliquity variation which is proportional to the cosine function [1]. The flux emitted from the source plane will therefore be given by:

$$\omega(\theta)\, d\theta = A \cos\theta \; d\theta \qquad \text{(B-1)}$$

[1] This corresponds to the angular dependence given on Page 9 of FM-100-1, Supplement No. 1, (Reference B-1).

FIGURE B-1

Bulk Shield With Through-Hole



where θ is the angle between the normal to the wall and the emergent radiation, and A is a normalization constant.

For the purposes of this investigation, the source plane will be considered to be adjacent to the bulk shield. Therefore, the source seen by the bulk shield will be given by Equation (B-1) where $0 \leq \theta \leq \frac{\pi}{2}$.

The radiation penetrating the shield will consist of several components. First, there is the radiation that penetrates all solid material. Next, there is the radiation that streams down the hole in the shield without coming in contact with solid material. Then, there is the radiation which passes down the hole after scattering from the material around the hole. Finally, there is radiation which starts out either in the hole and passes

into solid material or starts out in solid material and penetrates to the hole, subsequently passing through the shield.

Also, of course, there is radiation which is multiply affected as it traverses the shield; for instance that which starts out in the hole, passes into the solid and sometime later is rescattered into the hole. However, this type of radiation will have undergone second order interactions which, because of their small probability of occurrence, will be omitted from consideration in this discussion. The effect of decrease in barrier thickness due to holes through the solid material will, however, be taken into account.

The angular distribution of the flux is described by (B-1); however, the constant A is to be determined. For this problem, the flux at the source plane will be normalized to Φ_s photons per unit area. Then

$$\Phi_s = \int_0^{2\pi} \int_0^{\pi/2} \omega(\theta) \sin\theta \, d\theta d\gamma \qquad \text{(B-2)}$$

$$= 2\pi A \int_0^1 \cos\theta \, d(\cos\theta) = \pi A$$

or

$$A = \frac{\Phi_s}{\pi} \qquad \text{(B-3)}$$

where the integration is carried over the forward hemisphere only. Thus, Equation (B-1) becomes

$$\omega(\theta)\, d\theta = \frac{\Phi_s}{\pi} \cos\theta d\theta \qquad \text{(B-4)}$$

The radiation passing through the solid material in a bulk shield to a detector of area D can be described by

$$D \int_0^{\Omega_s} \frac{\Phi_s}{\pi} \cos\theta \, B(X \cdot V_f)\, (1-A_p)\, d\Omega$$

$$= D\Phi_s\, B(X \cdot V_f)\, (1-A_p)\, (1-\cos^2 \Phi_s^{max}) \ , \qquad \text{(B-5)}$$

where Ω_s is the solid angle subtended by the source at the detector, θ_s^{max} is the maximum half-angle corresponding to Ω_s, V_f is the fraction of the volume of the bulk shield occupied by <u>solid material</u>, and A_p is the fraction of the bulk shield surface, facing the source plane, which is aperture; i.e., through-holes. $B(X \cdot V_f)$ is the barrier factor for the solid material; X is the mass thickness of solid material and $X \cdot V_f$ is the mass thickness of the solid material available in the shield.[2/]

Radiation passing through an aperture (through-hole) without collision with the aperture walls to a detector of area D at the other end is given by

$$D \int_0^{\Omega_{A_p}} \frac{\Phi_s}{\pi} \cos\theta \, d\Omega \ . \qquad \text{(B-6)}$$

where ΩA_p is the solid angle subtended by one end of the aperture at the other end.

[2/] In determining $X \cdot V_f$ for a combination of materials, one forms the sum $X \cdot V_f = \sum_i (X_i \cdot V_{f_i})$.

If it is assumed that the detector is in the most exposed position; i.e., that the source plane seen through the aperture subtends the maximum solid angle possible--then Equation (B-6) gives the maximum dose that can be received by the detector. In this case, Equation (B-6) integrates to

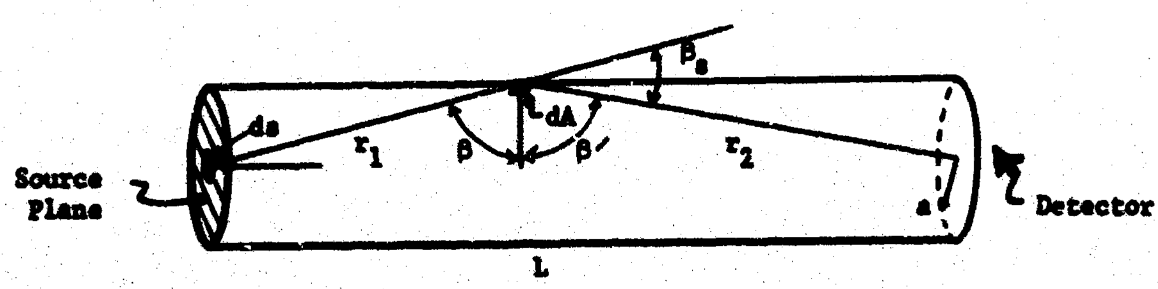
$$\theta_s DA_p \ (1-\cos^2 \theta_{A_p}^{max}) \qquad \text{(B-7)}$$

where $\theta_{A_p}^{max}$ is the maximum half-angle that can be subtended by the portion of source plane seen by the detector through an aperture--corresponding to the solid angle Ω_{A_p}. The other quantities are as defined above.

The radiation which passes through the apertures after colliding with and being scattered from the aperture walls will depend on the albedo of the solid material. The geometry of the problem is indicated in Figure B-2.

FIGURE B-2

Aperture Wall Scattering Geometry



The radiation leaving the area element of the source plane, ds, which reaches the area element of the aperture wall, dA, is given by

$$\frac{\omega(\theta)\ ds\ dA\ \cos\beta}{r_1^2} \quad . \qquad \text{(B-8)}$$

The flux reflected or re-emitted from dA is a fraction α of that falling on dA. α is known as the albedo and is a function of the energy and angle of incidence of the radiation. Assuming the reflected radiation is isotropic, the flux which reaches a detector of Area D at the end of the aperture is given by

$$\int_A \int_S \frac{\omega(\theta)\cos\beta}{r_1^2}\ \alpha(\beta,E)\ \frac{D}{2\pi r_2^2}\ dSdA \quad . \qquad \text{(B-9)}$$

To account for multiple scattering of neutrons in ducts, α is replaced by $\frac{\alpha}{1-\alpha}$ (Reference B-2). This formulation can also be used for gamma radiation to give an approximation of the effect of multiple interactions. Then Equation (B-9) becomes

$$\int_A \int_S \omega(\theta)\ \frac{\cos\beta}{r_1^2}\ \frac{\alpha}{1-\alpha}\ \frac{D}{2\pi r_2^2}\ dSdA \qquad \text{(B-10)}$$

where $\alpha = \alpha(\beta,E)$.

Inasmuch as we are investigating shielding characteristics, and the effects of holes, we can look at a worst case for radiation dose calculation. This will occur when the detector is the size of the aperture and adjacent to the bulk shield. In this case, $D = \pi a^2$.

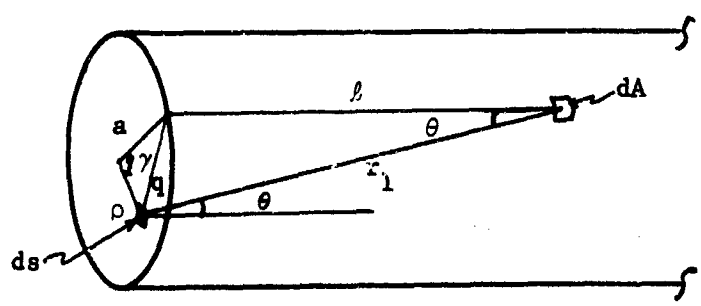
From Figure B-2 it is seen that $\cos\beta = \sin\theta$. Therefore, Equation (B-10) becomes

$$\int_A \int_S \frac{\Phi s}{\pi} \cos\theta \frac{\sin\theta}{r_1^2} \frac{\alpha}{1-\alpha} \frac{\pi a^2}{2\pi r_2^2} \, dSdA \quad . \qquad \text{(B-11)}$$

In order to reduce the functional dependence of the variables in Equation (B-11), we must define more geometric quantities. Figure B-3 shows the quantities with which we will be concerned.

FIGURE B-3

Description of Integration Variables



From Figure B-3, $r_1 = \ell \sec\theta$, $ds = \rho d\gamma d\rho$, $\tan\theta = q/\ell$, and $q^2 = a^2 + \rho^2 - 2a\rho\cos\gamma$. Therefore, $\ell^2\tan^2\theta = a^2 + \rho^2 - 2a\rho\cos\gamma$. Also $dA = a d\gamma d\ell$. Substituting these quantities into (B-11), yields

$$\frac{\Phi_s a^2}{2\pi}\int_A\left[\int_S \frac{\cos^3\theta\sin\theta}{\ell^2}\frac{\alpha}{1-\alpha}\frac{1}{r_2^2}\rho d\gamma d\rho\right] a d\gamma d\ell \quad . \qquad \text{(B-12)}$$

From above, $\tan\theta = \frac{1}{\ell}\sqrt{a^2+\rho^2-2a\rho\cos\gamma} = \sqrt{\sec^2\theta - 1}$

Therefore, $\sec^2\theta = 1 + \frac{1}{\ell^2}(a^2+\rho^2-2a\rho\cos\gamma)$ and making the approximation that $L-\ell = r_2$, (B-12) becomes

$$\frac{\Phi_s a^2}{2\pi}\int_0^L\int_0^{2\pi}\int_0^a\int_0^{2\pi}\frac{\left\{1-\frac{1}{1+\frac{1}{\ell^2}(a^2+\rho^2-2a\rho\cos\gamma)}\right\}^{1/2}}{\ell^2\left\{1+\frac{1}{\ell^2}(a^2+\rho^2-2a\rho\cos\gamma)\right\}^{3/2}}\cdot\frac{\alpha}{1-\alpha}$$

$$\cdot\frac{1}{(L-\ell)^2}\rho a\, d\gamma d\rho d\gamma d\ell \qquad \text{(B-13)}$$

which looks ferocious.

Equation (B-13) will give the portion of the radiation streaming down an aperture which is scattered at the aperture walls. In its present form, the integration would have to be done numerically, but some simplifying assumptions, which are yet conservative as pertains to shielding, will make the problem much more amenable to solution. We thus assume that the entire source plane is replaced by a point source of equal intensity and angular dependence on the axis at the end of the cylinder. The strength of this

point source will be $\pi a^2 \Phi_s$. The quantity r_1 , will then be $r_1 = a \csc \theta$ and, as before r_2 will be approximated by $L - \ell$. Then Equation (B-11) becomes

$$\int_L \Phi_s a^2 \frac{\cos \theta \sin \theta}{a^2 \csc^2 \theta} \frac{\alpha}{1 - \alpha} \frac{a^2}{(L - \ell)^2} \pi a d\ell \quad . \qquad \text{(B-14)}$$

We now make the approximation that the through-holes we are considering have the ratio $a/L \ll 1$. This being the case, the quantity $(L - \ell)^2$ in the denominator of (B-14) can be conservatively replaced by $(L^2/4)$.[3/] Then the number of photons which pass through an aperture to a detector of area D after scattering from a wall one or more times will be given approximately by (since $a \cot\theta = \ell$ and therefore $-\csc^2 \theta d\theta = d\ell$):

$$\frac{4\Phi_s \pi a^4}{L^2} D \int_0^{\pi/2} \sin \theta \frac{\alpha}{1 - \alpha} d(\sin \theta)$$

$$= \frac{D_2^2 \Phi_s \pi a^4}{L^2} \frac{\widetilde{\alpha}}{1 - \alpha} = \frac{D^2 4\Phi_s Ap\, a^2}{L^2} \frac{\widetilde{\alpha}}{1 - \alpha} \qquad \text{(B-15)}$$

where $Ap = N \pi a^2/WH$, N is the number of holes of area πa^2 in a surface of width W and height H, and $\frac{\widetilde{\alpha}}{1 - \alpha}$ is an average value for the albedo function at energy E. To pick a value for the albedo function, consider the distance down a tube an "average" photon will go before colliding with a wall. This is given by

3/ This corresponds to saying that by the time the integration has covered half the length of the duct, the angle θ is so small the rest of the length makes only a small contribution to the integral.

$$\bar{\ell} = \frac{\rho \cos\theta\, \ell\, d\,\Omega}{\cos\theta\, d\,\Omega} = a \frac{\int_0^{\pi/2} \cos^2\theta\, d\theta}{\int_0^{\pi/2} \sin\theta \cos\theta\, d\theta} \tag{B-16}$$

$$= a \frac{\left[\frac{1}{2}\theta + \frac{1}{2} \sin\theta \cos\theta\right]_0^{\pi/2}}{\left[\frac{\sin^2\theta}{2}\right]_0^{\pi/2}} = \frac{\pi a}{2} = 1.57a \quad .$$

This corresponds to the average photon impinging on the tube wall at an angle of 57.5 degrees.

According to Shoemaker and Huddleston (as reported by Barrett and Waldman, Reference B-3), if one uses the dose albedo approximated by the Chilton — Huddleston formula (Reference B-4), there is no need to measure the albedo for other than coplaner incident and scattered radiation. This is true since the value of the albedo for a given set of incident, reflection, and scattering angles is independent of the plane of incidence and plane of reflection. The Chilton-Huddleston formula is:

$$\alpha\,(\Omega) = \frac{C\, K(\beta_s) \quad 10^{26} + C'}{L + \cos\beta \sec\beta'} \tag{B-17}$$

where C and C' are fitting constants determined by the backscattering material and the incident photon energy; $K(\beta_s)$ is the Klein-Nishina value of the energy scattering cross-section per electron, per steradian about the scattering angle β_s. β is the angle of the incident photon with the normal and β' is the angle with the normal of the scattered photon (cf. Figure B-2). The conclusions of the work of Barrett and Waldman (Reference B-3)

indicate that Equation (B-17) does adequately describe the differential albedo. Therefore, we can use their data for coplanar incidence and reflection and determine a dose albedo.

For $\beta = 60^o$, assuming coplanar incident and emission angles, $\beta' = 180-60-\beta_s = 120-\beta_s$. Then for CO^{60} gammas reflected from iron, Reference B-3 gives:

β_s (degrees)	β' (degrees)	$10^3\ \alpha\ (60,\beta')$	$\sin\beta'$	$\alpha \times 10^3 \times \sin\beta'$	β' (radians)
50	70	33.08	.94	31.05	1.21
60	60	30.53	.866	26.4	1.05
70	50	25.51	.766	16.4	.875
100	20	17.04	.342	5.82	.3495
110	10	15.38	.174	2.67	.1743

The total albedo for photons incident at 60^o is obtained by integrating over all directions which contribute to the reflected radiation. Using the above data a numerical integration gives $\alpha_p\ (60^o) = \int_0^{\pi/2} \alpha(\beta') \sin\beta'\, d\beta' = 27.6 \times 10^{-3}$, a constant, where α_p indicates coplanar incidence and reflection. Assuming that α_p is independent of direction of reflection,[4/] the total albedo is given by:

$$\alpha = 2\pi \times 27.6 \times 10^{-3} = .173 \quad .$$

[4/] This is a conservative assumption, the albedo is greatest for forward scattering, coplanar incidence and reflection represent the maximum forward scattering angle for a particular angle of reflection. Therefore, the albedo calculated on this assumption is a maximum and the effect is to emphasize the magnitude of radiation streaming in a duct.

Therefore, the total dose albedo from iron for forward scattered 1.25 mev photons is approximately 0.17 for an incident angle of 60°. This quantity is in rough agreement with the data of Berger and Raso (as reported by Terrell and Jerri, Reference B-5) for 0.5 mev photons reflected by concrete.

This α is of sufficient accuracy to estimate the effect of duct wall scatter for photons incident at 57.5°. The streaming of photons down an aperture after wall collision will thus be given by Equation (B-15) where $\frac{\widetilde{\alpha}}{1 - \alpha}$ has the value 0.205.

We now consider the case of radiation which starts out either in a hole and passes into solid material, or which starts out in solid material and penetrates to a hole. Since the holes being considered have $L/a \gg 1$, and since before collision with a wall the average photon travels a distance down a hole $\bar{l}$ which is small compared to L ($\bar{l}$ = 1.57a for photons with their source on the axis of the hole), and since the percent of radiation reflected at a wall is small (α = 0.17, from above), many simplifications are available to the problem. First of all, since the distance traversed by a photon in a hole is small compared to the overall length of the shield, the flight distance in the hole can be neglected. However, the average photon also travels at an angle of 32.5 degrees with the axis of the hole and thus its straight line path through the shield is approximately $d = L \sec 32.5^\circ$. Also, since the albedos of iron, concrete, and other materials of which a bulk shields are likely to be constructed all are rather small, we can, to a good approximation consider that the apertures (through-holes) have no effect on the attenuation of the shield except to reduce its mass thickness; i.e., for this calculation,

we ignore the fact some of the photons stream down the holes. Therefore, for radiation starting in a hole and passing into solid material, the radiation transmitted by the shield to a detector of area D will be given approximately by

$$D\,A_p \int_0^{\Omega_s} \frac{\Phi_s}{\pi} \cos\theta B(X\cdot\sec\bar{\theta}\cdot V_f)\, d\Omega$$

$$= D\,A_p\,\Phi_s B(X\cdot\sec\bar{\theta}\cdot V_f)\ (1 - \cos^2\theta_s^{max}) \qquad \text{(B-18)}$$

where $\bar{\theta}$ is the average obliquity angle of the radiation incident on the aperture--32.5 degrees for the cosine distribution given above, Ω_s is the maximum solid angle subtended by the source plane at the detector, and θ_s^{max} is the corresponding maximum half-angle.

The radiation which enters the solid material but later encounters a hole and streams down the hole will be a small factor because of the low gamma albedos. The only effect that has to be considered is the effective decrease of the mean paths through a bulk shield. However, as shown above, this effect is negligible for radiation incident on the hole from the source and the effect should be negligible in this case also. All other effects of the decrease in mass thickness have been accounted for in the volume fraction term included in Equation (B-5). Therefore, a term to account specifically for flux entering the shield through the solid portion and subsequently scattered down a through-hole may be omitted from consideration.

Including all of the significant contributors to dose rate at a detector of area D, from Equations (B-5), (B-7), (B-15), and (B-18); the total exposure, E, at the end of a bulk shield, is given by

$$E = \Big\{ \Phi_s\, B(X \cdot V_f)\,(1 - Ap)\,(1 - \cos^2 \theta_s^{max}) + \Phi_s\, Ap\,(1 - \cos^2 \theta_s^{max})$$

$$+ \frac{2_s Ap\, a^2}{L^2}\, \frac{\alpha}{1 - \alpha} + Ap\, \Phi_s\, B(X \cdot \sec \bar{\theta} \cdot V_f)\,(1 - \cos^2 \theta_s^{max}) \Big\}\, D$$

$$= D\Phi_s \Big\{ [B\,(X \cdot V_f)\,(1 - Ap) + B(X \cdot \sec \bar{\theta} \cdot V_f)\, Ap]\,(1 - \cos^2 \theta_s^{max})$$

$$+ Ap\,(1 - \cos^2 \theta_{A_p}^{max}) + 2\, \frac{a^2}{L^2}\, Ap\, \frac{\alpha}{1 - \alpha} \Big\} \quad \text{photons}/\text{sec}. \qquad \text{(B-19)}$$

III. DISCUSSION

It has been assumed that a barrier factor, B $(\bar{X})$ can be obtained for the case considered, i.e., for a cosine flux distribution from a limited plane source. Spencer (Reference B-6) has calculated barrier factors, L (c) and L(X) for an infinite medium of air as a function of distance in air above an infinite plane uniformly covered with isotropic point sources. Also, Spencer (op. cit.) gives curves for dose angular distributions, ℓ (d, $\cos\theta$) for radiation above the plane. The curve for ℓ (d, $\cos\theta$) given for d = 1200 feet is very nearly a cosine function for the forward component ($\cos\theta > 0$). Therefore, the curve given by Spencer for L (D) can be used

for the infinite medium barrier factor with a cosine source distribution by renormalizing to the 1200 ft. ($X = \frac{1200}{13.3}$ 5/ psf = 90.2 psf) point. For the geometries with which we are concerned (several path lengths of shield thickness), the radiation intensity received by a detector at a constant distance from a source plane is proportional to the solid angle subtended by the source times the radiation emitted into this solid angle. This fact is included in the present formulation by the integrations in Equations (B-5) and (B-18) for, in effect, these integrations take the ratio of radiation emitted by a particular source plane to that emitted by an infinite plane. Within the accuracy of the calculations, the finite media with which we are concerned are well represented by considering them as fractions of infinite media. The appropriate barrier factor for the present application is obtained by taking the ratio of the barrier factors L(X) given by Spencer for 90 psf and for $X \cdot V_f$ + 90 psf:

$$B(\bar{X}) = \frac{L(\bar{X} + 90 \text{ psf})}{L(90 \text{ psf})} \qquad \text{(B-20)}$$

where $\bar{X} = X \cdot V_f$ is the argument of the barrier factors appearing in Equation (B-19).

Equation (B-19) gives an expression for the total exposure, E, of a detector to radiation coming through a bulk shield. We now investigate the relative magnitudes of the terms in this equation. A typical piece of massive machinery providing bulk shielding will probably be constructed primarily of iron. The characteristics of heavy machinery vary considerably. A large diesel engine might have a volume fraction of from 5 to 10 percent iron; a large generator might run from 20 to 30 percent iron. (The other solid materials are included

5/ 13.3 feet in air is equal to one psf.

in these numbers--iron is assumed to be the equivalent of other metals as far as gamma radiation is concerned). For our purposes, we will consider a generator.

A large generator will be about 20 feet long, 10 feet wide, and 10 feet high--of which about 7 feet will be above floor level. These generators are completely enclosed with a steel pressure shell about three inches thick. However, since we are trying to evaluate the importance of terms in Equation (B-19), this shield will be ignored. Of the twenty-foot length, about two feet on each end will be essentially empty. Then there will be about thirty 6-inch ducts passing through the machinery parallel to th axis. The overall volume fraction of iron will be about 30%. Therefore, we have the following characteristics:

$X = (0.931)\ (480)\ (20)$ psf $= 894$ psf (assuming solid iron, 20 feet thick)

$V_f = 0.30$

$A_p = \dfrac{30\pi\ (.25)^2}{100} = 0.06$

$a = 0.25$ ft.

$L = 20$ ft.

$\dfrac{\widetilde{\alpha}}{1 - \alpha} = 0.205$

$\bar{\theta} = 32.5^\circ = 0.567$ rad.

$\theta_{Ap}^{max} = \dfrac{0.25}{20} = 0.0125$ rad.

$\theta_{Ap}^{max} = \tan^{-1}\ \dfrac{5}{20} = 14^\circ = 0.244$ rad.

using these quantities,

$X \cdot V_f = 268$ psf

$X \sec \bar{\theta} \cdot V_f = 318$ psf

and from Equation (B-20), using L(X) of Spencer (Reference B-6),

$$B\ (268\ \text{psf}) = \frac{L\ (268 + 90\ \text{psf})}{L\ (90\ \text{psf})} = \frac{5.2 \times 10^{-5}}{2.6 \times 10^{-2}} = 2.0 \times 10^{-3}$$

and

$$B\ (318\ \text{psf}) = \frac{1.9 \times 10^{-5}}{2.6 \times 10^{-2}} = 7.3 \times 10^{-4} \quad .$$

We now evaluate Equation (B-19), term by term:

$$B\ (X \cdot V_f)\ (1 - Ap)\ (1 - \cos^2 \theta_s^{max}) = (2.0 \times 10^{-3})\ (0.94)\ (0.06) = 1.12 \times 10^{-4}$$

$$B\ (X \sec \bar{\theta} \cdot V_f)\ Ap\ (1 - \cos^2 \theta_s^{max}) = (7.3 \times 10^{-4})\ (0.06)\ (0.06) = 2.62 \times 10^{-6}$$

$$(1 - \cos^2 \theta_{Ap}^{max})\ Ap = (1 - (0.99992)^2)\ (0.06) = (1.6 \times 10^{-4})\ (0.06) = 9.6 \times 10^{-6}$$

$$2 \frac{a^2}{L^2}\ Ap\ \widetilde{\frac{\alpha}{1 - \alpha}} = 2 \left(\frac{.25}{20}\right)^2\ (0.06)\ (0.205) = 2\ (1.56 \times 10^{-4})\ (0.06)\ (0.205)$$

$$= 3.76 \times 10^{-6}$$

The largest component is therefore seen to be $B\ (X \cdot V_f)\ (1-Ap)\ (1 - \cos^2 \theta_s^{max})$ which is due to transmission through the solid material. The other contributors to radiation dose are seen to be smaller than this component by more than an order of magnitude.

The situation calculated in the above example is believed to be a worst case, i.e., will maximize the importance of radiation streaming. Even here, the effect of through-holes is small. Since enclosures of voids inside a

machine will be of less importance than through-holes, aside from their effect on volume fraction and thus on B $(\bar{X})$, these will also have small effects. Therefore, the shielding afforded by bulk materials can be accounted for to a good approximation by homogenizing the solid material over the volume of the shield, ignoring effects of voids and ducts other than that included in specifying the volume fraction, V_f, of the solid material present.

The exposure E will then be given by:

$$E = D \, \Phi_s \, B \, (X \cdot V_f) \, (1 - \cos^2 \theta_s^{max}) \quad , \qquad \text{(B-21)}$$

where $B(X \cdot V_f)$ is computed for a cosine distribution as shown in Equation (B-20).

However, even though a bulk shield is homogenized for calculational purposes, through-holes will cause local hot-spots of radiation; they should therefore be avoided by persons in a shelter which utilizes bulk shielding.

IV. COMPARISON WITH EXPERIMENT

Pratt and Kouts (Reference B-7) have measured the ratio of gamma radiation leaking through a water shield containing cylindrical voids to that leaking through a shield containing no voids. The voids considered consisted of 2, 4, 6, 8, 12, and 18 inch diameter cylinders with lengths varying from 84 to 143 inches for the smallest diameter and 24 to 48 inches for the largest. Measurements were made using both GM counters and ion chambers. The gamma source was a natural uranium plate mounted over a reactor in the BNL water tank shielding facility. This supplied a source of fission gammas, most of

which have an average energy of one mev. This radiation is similar to that of fallout and the results of the experiment are thus comparable with the present calculations.

The water tank in which the experiments were run was about 12 feet high and 5 feet wide. All of the cylindrical voids had their axes in the vertical direction with their upper ends at the top of the water tank (the source plate completely covered the bottom).

Since the ion chamber response roughly approximates the dose received by tissue, the data taken with this instrument were used for the present comparison. The flux profile across the top of each cylindrical void was determined and the results presented in Reference B-7 in graphical and tabular form.

We used the data from Reference B-7 in the following manner. For each cylindrical void diameter, the peaks of the flux ratios[6/] observed at the top of the voids were plotted as a function of void length. The value that would be observed for cylindrical voids of 100 inches length were then obtained by interpolation. Then the flux ratios were plotted as a function of cylinder diameter for the 100 inch void length and the results extrapolated to 61-inch diameter (the diameter of the water tank). This gave the ratio of the flux observed with the tank filled to a depth of 43 inches to that with it completely filled. Next, the plots of flux ratio for each diameter void were extrapolated to a void of sufficient length to pass completely through the water tank.

[6/] The flux measurements were made as a function of position across the top of the voids. The data were presented on a ratio of the flux observed at each position over the void to that observed in the same position with no void present. This forms a flux ratio curve. The peak of this curve corresponds to the present calculations.

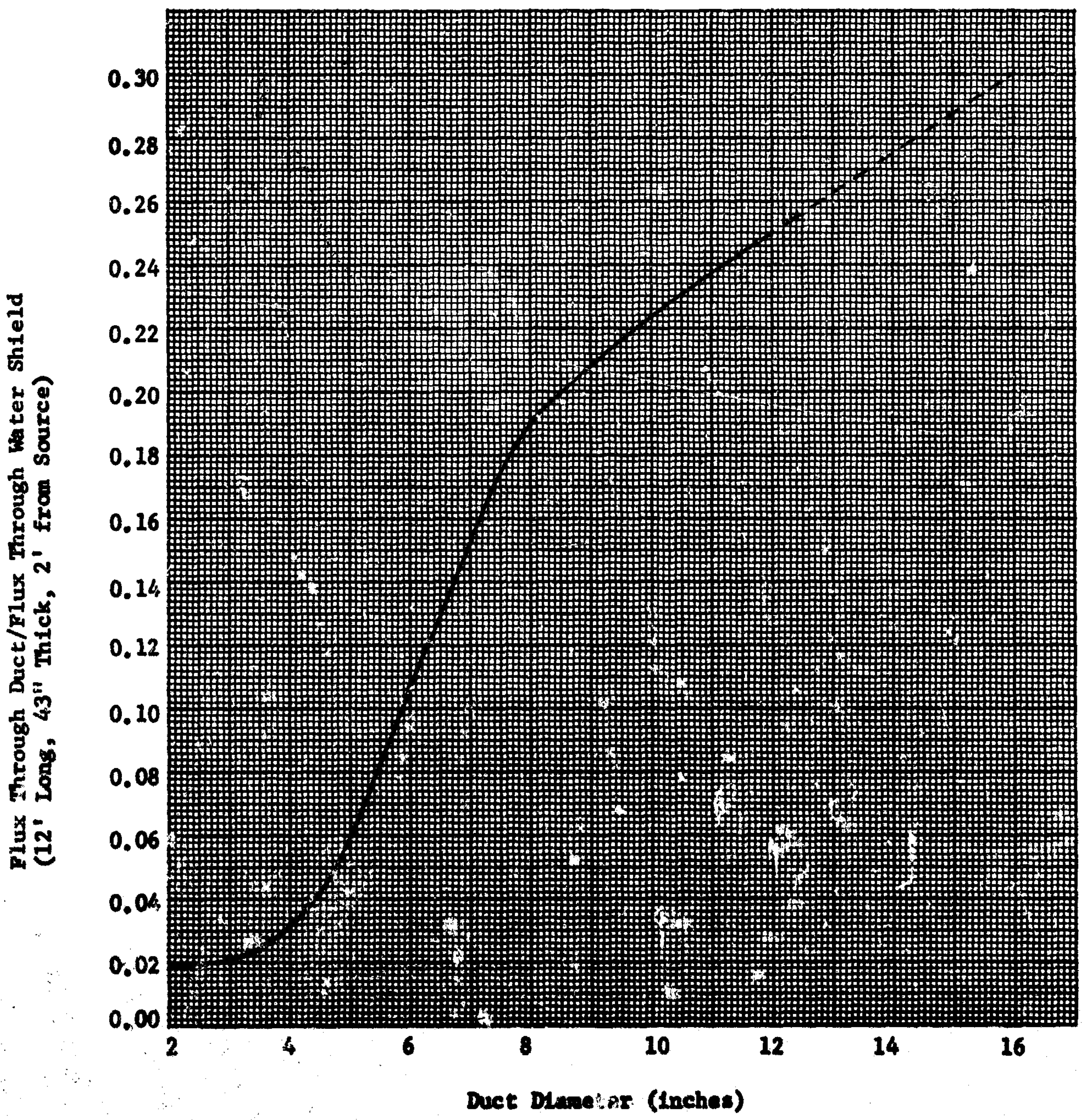
Finally, this full length void ratio was divided by the partially filled tank ratio. The results gave the ratio of the flux observed through a cylindrical through-hole of various diameters to that observed through a water shield of 248 psf (30 percent of that of the full tank mass thickness). The results of these calculations are shown in Figure B-4.

The point for the 18" duct is not included in Figure B-4 since there were insufficient measurements made for this diameter to reliably extrapolate the data to obtain the results for a duct 12 feet in length.

If the barrier slab had been homogenized over the whole 12-foot distance between source and detector, instead of contained in the area adjacent to the source, the results would have been somewhat different. Also, had the 12-foot duct passed through the homogenized material rather than that of 100 percent density, the answers would have varied to a degree. However, the effects would not alter the conclusions that obtain from Figure B-4. From this figure it is seen that for a duct one foot in diameter, by 12 feet long in a 30 percent dense material, a 25 percent increase in radiation will be observed AT THE MOUTH OF THE DUCT. Therefore, one should always avoid open ducts. However, the duct itself comprises only 4 percent of the shield volume and thus the total radiation passing through a bulk shield is not greatly affected by the presence of ducts provided one is either some distance from the shield, or not directly in front of a hole. It should also be noted that a 12-inch through-hole in bulk shielding is not very common, and for the much smaller holes that usually occur (2 to 6 inch diameter) Figure B-4 indicates 11 percent or less increase in flux at the end of the hole.

FIGURE B-4

Flux Ratio Curve



A calculation was performed using Equation (B-19) for the relative exposure expected through the 30% dense water shield with various aperture fractions. The calculations gave aperture affects which are somewhat higher than indicated by experimental data. These calculations assumed a cosine distribution of the radiation at the source plane. In the experiment, the source plane radiation was probably not as forward peaked as that given by a cosine function. This leads one to expect that the calculations should over-estimate the duct effects. However, the results given by the theoretical treatment are sufficiently greater than the experimental data for the theoretical approach to be considered conservative independent of the source distribution of the experiment.

The calculations evaluating the relative importance of the terms in Equation B-19 indicated that the homogenized solid material term is of primary significance. The additional terms, accounting for duct streaming, were found to be relatively unimportant. These unimportant terms are, however, the ones which in comparison of calculated and experimental results were found to be over-estimated by the theory. The conclusion that these terms may be neglected in evaluating shielding characteristics of bulk material is therefore more conservative than indicated by the theoretical evaluation.

Thus, Equation (B-21) will, to a good approximation, give the shielding to be afforded by bulk material; the reservation should be made, however, that through-holes are still to be avoided.

V. APPLICATION OF RESULTS

As indicated above, shielding afforded by bulk material can, to a good approximation, be accounted for by homogenizing the material over the volume it occupies. In the determination of this result, a cosine distribution slab source was assumed. This distribution is approximately what would be expected inside a heavy slab (90 psf), covered with uniform contamination. In most cases, the wall of a building is not heavy enough to cause a forward peaking of the flux distribution to the extent given by the cosine function. Therefore, since a forward peaked distribution emphasizes the importance of holes and voids in a radiation shield, the conclusion reached, using the cosine distribution, that bulk material can be homogenized, is conservative.

In the application of the results obtained here, Equation (B-21) will give the exposure due to radiation emitted from the <u>inside</u> of a wall. However, instead of calculating this emitted radiation and subsequently finding the exposure, a more direct method of obtaining shielding afforded by bulk material is to merely add to the wall mass thickness the homogenized mass thickness of the bulk material and proceed with shelter calculations in the usual fashion.

One caution should be observed. In a sector analysis of a shelter, the homogenized bulk shield material added to the wall should subtend the same azimuthal angle at the detector as the actual bulk shield.

Also, the height of the bulk shield must not be changed. This is generally conservative, but homogenizing the bulk material over an entire wall height in a sector would often be definitely non-conservative.

Therefore, in applying the homogenization procedure to engineering calculations, the mass of the shield is added to the mass of the wall keeping the height of the bulk mass and the angle it subtends at the detector position constant.

APPENDIX B REFERENCES

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APPENDIX C

Description of Surveyed Key Facilities

This Appendix contains descriptions of the 26 key facilities surveyed to identify special shielding problems and to determine the importance of special equipment or interior contents in ascertaining the shelter capability for certain critical operations. Included are exterior photographs, indications of the essential functions performed, type of construction, and the protection factors determined by the Key Facility PF Computer Program.

BUILDING NO. 1

Fiveash Water Treatment Plant
Powerline Road
Fort Lauderdale, Florida

Exterior View

Function

This facility is the main water treatment and pumping plant for the city of Fort Lauderdale. It has storage tanks that hold 7½ million gallons of water, and the average consumption in Fort Lauderdale is 12 million gallons per day. All functions are controlled from a room on the top story of this two-story building.

Construction

This building is of all concrete construction. Many of the floors, walls, etc., are quite thick due to the weight of water in tanks. The control point, however, is on the top story of the plant and has a number of windows.

Protection

Although some PF 1000 or better space is available in a basement area, the PF at the control panel is very low (12) and someone is required in this location at almost all times.

BUILDING NO. 2

Fort Lauderdale Water Department
(Dixie Plant)
State Road Number 7
Fort Lauderdale, Florida

Exterior View

Function

This facility, although only one-third the size of the Fiveash Plant, is a critical water pumping and treatment station for Fort Lauderdale. The critical water pressure controls are located in the front one-story building.

Construction

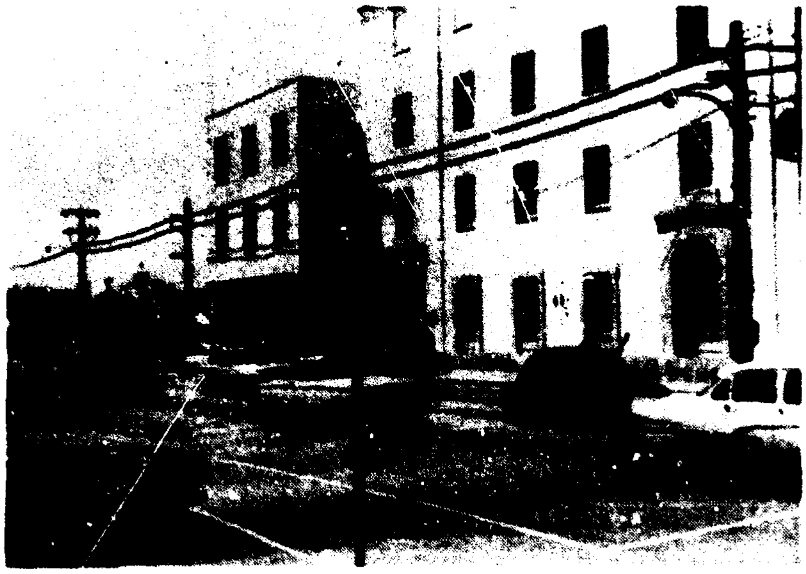
This building has a concrete frame, and part of the exterior walls are concrete. The part containing the operating controls has brick walls with a part-wood part-concrete roof.

Protection

The PF at the control point is only 15 due to the rather open construction.

BUILDING NO. 3

Southern Bell Telephone Co.
115 N.E. 3rd Avenue
Fort Lauderdale, Florida



Exterior View

Function

This building houses the telephone exchange for Fort Lauderdale. It contains the telephone operators and the engineers necessary to maintain the automatic dialing system. These engineers, necessary in order to maintain communications during an emergency period, are located on various stories of the building.

Construction

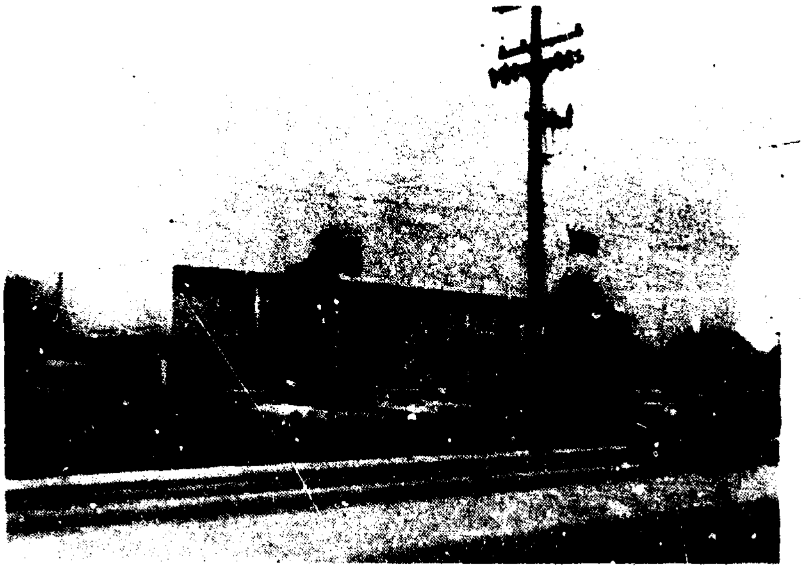
This building is a four-story concrete-frame building with heavy concrete floors and thick brick and stucco exterior walls. Every story contains large amounts of equipment.

Protection

The PF at the critical operating point for the automatic system on the second floor is quite good (300), due primarily to the heavy walls, overhead floors, and roof. The equipment and small apertures also contribute to overall protection. The building contains its own emergency power plant and has some potable water.

BUILDING NO. 4

Municipal Court Building (Police)
1300 W. Broward Boulevard
Fort Lauderdale, Florida



Exterior View

Function

This building contains the police department, the police communications switchboard, and the emergency city council communications office. It is therefore the center of communications in an emergency situation.

Construction

This is a two-story building with concrete frame, concrete floors and roof, masonry walls, and a partial basement. It does have quite a large percentage of windows on the first floor; however, the basement is almost completely underground.

Protection

The protection at the communications switchboard on the first story is quite low (7); however, directly below this switchboard is a basement shelter with a high PF (over 100) and complete emergency equipment (power, water, etc.).

BUILDING NO. 5

Florida Power and Light
Fort Lauderdale Station
Griffin Road
Fort Lauderdale, Florida

Note: Photographs of this building were not permitted.

Function

This station is one of the medium size electric power producing plants of the Florida Power and Light system. It furnishes power for Fort Lauderdale; however, it is possible to transfer power from other stations by remote control.

Construction

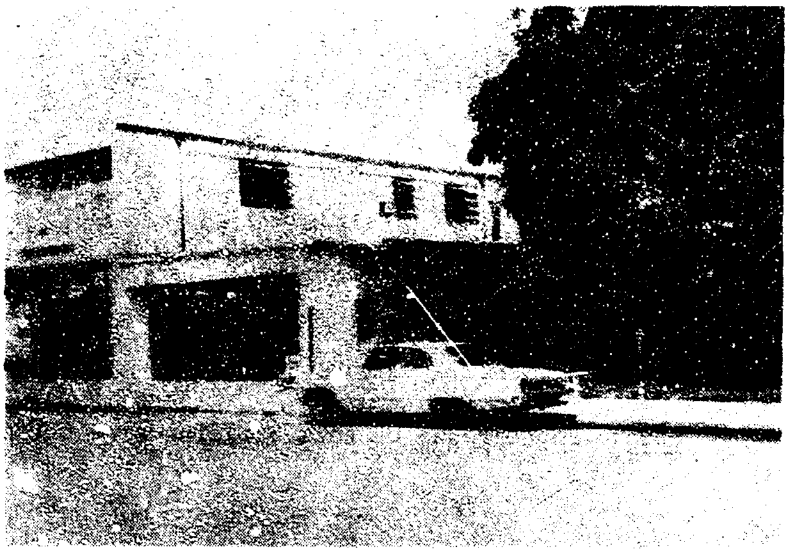
There are several buildings in this complex; the main building is a steel frame, steel wall building with steel floors and a corrugated steel roof.

Protection

The controls for this plant are in the second level of the main building where the boilers are located. This steel building provides a very low protection factor of 4.5 at the controls; however, a building nearby, which contains the electrical switching panel, is a very heavy concrete building with a PF in excess of 100.

BUILDING NO. 6

Fire Station Number One
N.W. 2nd Street
Fort Lauderdale, Florida



Exterior View

Function

This building is the central fire fighting center for the city of Fort Lauderdale. The central radio communications to the police and the other fire stations come through this office.

Construction

This building is a concrete frame building with walls of concrete block. The main part of the building is one story high; however, part of the structure is two stories. The roof is quite light in construction.

Protection

The protection factor is only 5, primarily due to the fact that the control point is located in the one story part of the structure and faces a large open area through a large window. Very few areas of this structure or adjacent structures would have adequate protection.

BUILDING NO. 7

Holy Cross Hospital
4701 N. Federal Highway
Fort Lauderdale, Florida

Exterior View

Function

This hospital is one of the largest hospitals in Fort Lauderdale. It serves as the nerve center for health and emergency health operations. The operating rooms on the third story were analyzed for protection against fallout.

Construction

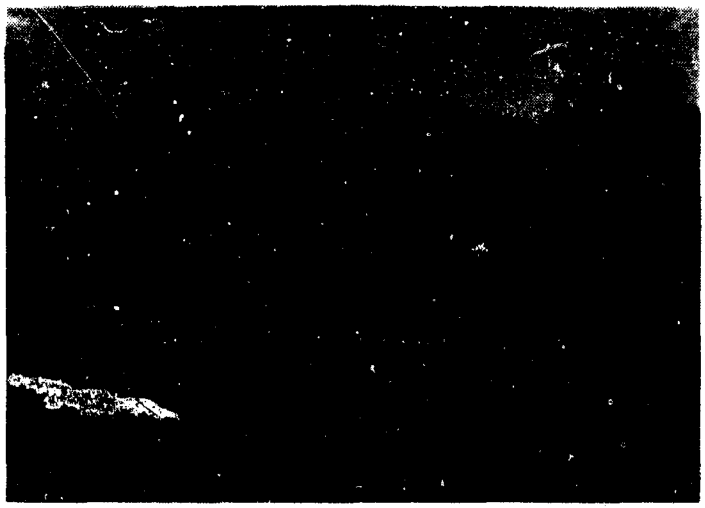
This is a large five-story building with a concrete frame, concrete floors and roof, and masonry walls. Almost all floors have extensive concrete block and glazed tile partitions.

Protection

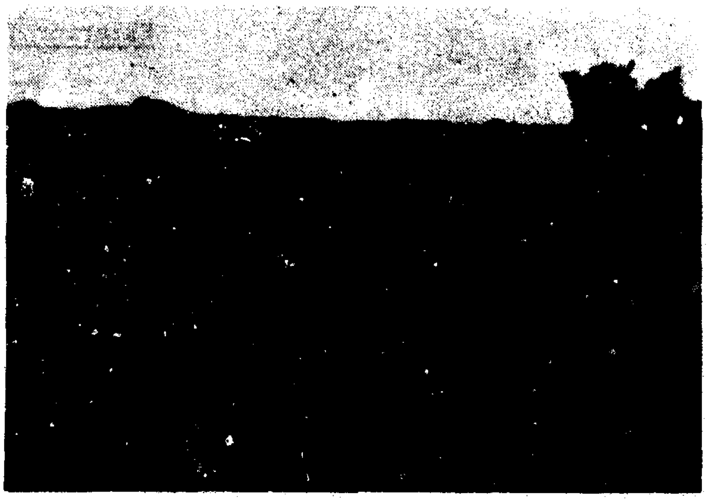
Primarily due to partitions and heavy floors, the PF on the third story is quite high (165) and this PF is typical of many areas in the building. The building also has an emergency power system.

BUILDING NO. 8

Tulsa Water Treatment Plant
Tulsa, Oklahoma



Main Building



Filter Control and Pump Buildings

Function

The Tulsa Water Treatment Plant supplies water for the city of Tulsa and surrounding area. The Main Building contains boilers and turbines for pumping water to the city. The boiler control panel (in the two story portion) and the turbine control panel (in the one story portion) must be manned constantly. The filter buildings contain the filter controls. Filter beds are both outside of the newer building in the foreground and inside the older building immediately behind the new one in the photograph. The filter controls must be checked periodically. In the left background of the photograph, there is a building that contains pumps which take the water from the lake (visible in background). These pumps must be checked periodically.

Construction

All of the buildings in the Water Treatment Plant complex have reinforced concrete walls with a brick veneer. The roofs are concrete.

Protection

Due to surrounding buildings, water settling basins, and relatively thick walls, the ground contribution was usually less significant than the overhead contribution. In the Main Building, the Boiler Control Area has a PF of 9 and the Turbine Control Area has a PF of 4. The New Filter Control Building has a PF of 9 while the Old Filter Control Building has a PF of 13.

BUILDING NO. 9

St. Francis Hospital
6161 S. Yale
Tulsa, Oklahoma

Front View

Function

St. Francis is a large, privately endowed hospital serving north-eastern Oklahoma. Three areas on the first story were analyzed; surgery, x-ray, and a laboratory.

Rear View

Construction

The hospital is a modern reinforced-concrete six-story building. As with most hospitals, the geometry is rather complex.

Protection

The surgery area was found to have a PF of 196, the X-ray area a PF of 37, and the laboratory a PF of 19. The NFSS showed all of these to be PF Category 2 (PF 40-69).

BUILDING NO. 10

Fire Alarm Building
Tulsa, Oklahoma

Exterior View

Function

The Municipal Fire Alarm Building receives all fire reports and dispatches firefighting equipment and men from the various fire stations throughout the city. The control panel must be continuously manned to direct firefighting operations in the city. The communications area is in the center of a one story octagonal shaped building.

Fire Control Panel

Construction

The building, which has lower one story wings on the front and sides, is constructed of 12 inch brick walls with concrete roof and floors. There is a partially exposed basement.

Protection

The PF in the communications area is 15 without contents and 16 with the interior contents.

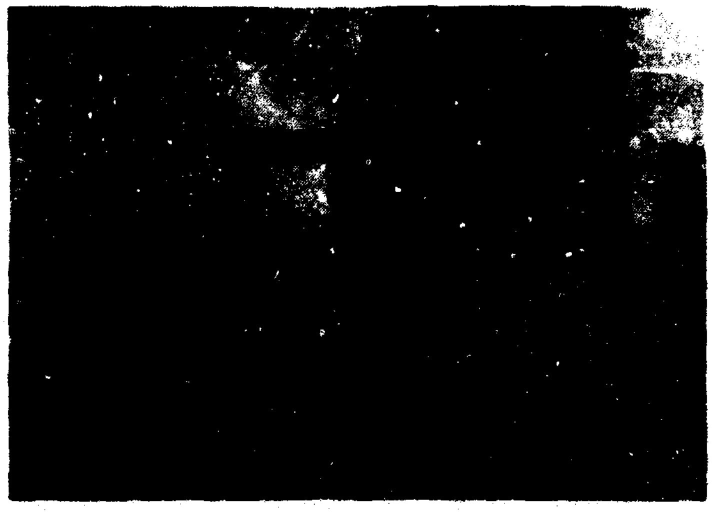
BUILDING NO. 11

Public Service Co. of Oklahoma
Tulsa Power Plant
Tulsa, Oklahoma

Administration Building

Function

The Tulsa Power Station supplies electric power to the Tulsa area, including the refinery complexes that surround the city. The plant contains three fairly new outside-type boilers and one older inside-type boiler. The plant also houses the dispatcher's office where the power demands from the Tulsa area are monitored. Both the new and the old control rooms, as well as the dispatching controls must be continuously manned.



Boiler and Turbine Area

Construction

The plant is constructed almost entirely of brick. The Dispatcher's Office and old control room are located on the second story of the two-story administration area in front of the plant. The new control room is located on the second story level between the boilers and turbine area.

Protection

The new control room has a PF of 35 with interior contents and 29 without contents. The old control room and Dispatcher's Office have PF calculations of 33 and 31 respectively. This facility was not surveyed in the NFSS. There are good basement shelter areas near the control rooms but they can only be reached by first going outside to reach the older building.

BUILDING NO. 12

Tulsa Police Communications
Municipal Court Building
401 S. Elgin Street
Tulsa, Oklahoma

Exterior View

Entrance to Communications Area

Function

The Tulsa Police Communications are headquarters in the basement of the Municipal Court Building. All police calls, by radio and telephone, are received in this room and the police officers are dispatched from there also.

Construction

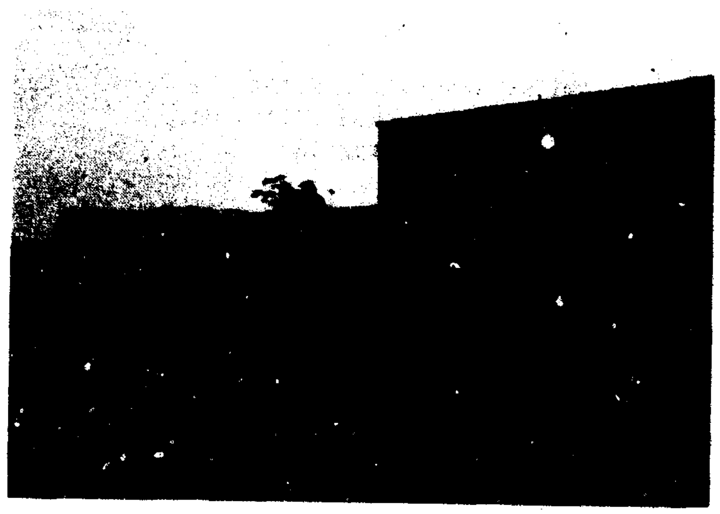
The communications area is located in the partially exposed basement of a two-story brick and stone building.

Protection

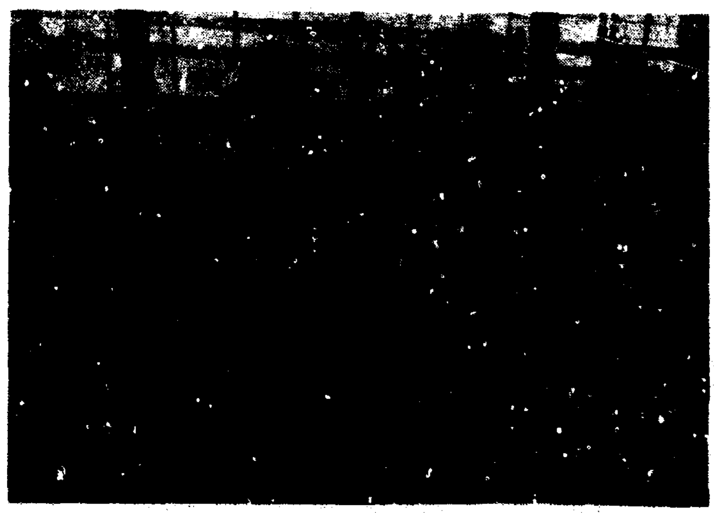
The PF of the Tulsa Police Communications Center is 52.

BUILDING NO. 13

Gas Compressor Plant No. 4
Gas Engineering Department
Long Beach, California



Exterior View



Control Panel

Function

Gas Compressor Plant No. 4 controls the dispensing of natural gas in the city of Long Beach. The control panel must be continuously monitored.

Construction

The plant is constructed of a structural steel frame and covered with transite.

Protection

The PF, both with and without using the contents of the building, was only 4. This is due to the large overhead roof contribution.

BUILDING NO. 14

Alamitos Generating Plant
Southern California Edison Co.
Long Beach, California

Note: Photographs of this building were not permitted.

Function

The Alamitos Generating Station is part of the Southern California Edison Company system, which supplies power to most of southern California. The plant consists of four gas fired boilers with a total output of 990 MW.

Construction

The control room of the power plant is constructed of 8-inch concrete block walls with reinforced concrete floors and roof of 8 inches and 6 inches respectively. In addition, the control room is shielded by the turbines and other equipment.

Protection

The PF of the control room is 37. The power plant was not surveyed by the NFSS.

BUILDING NO. 15

Long Beach Water Treatment Plant
3610 East Spring Street
Long Beach, California

Exterior View

Function

The Frank E. Wall Water Treatment Plant treats and pumps the water used by Long Beach and the surrounding communities. During an emergency it would be possible to pump directly from wells into the closed storage tanks and bypass the open treatment tanks. This would have to be controlled from the new pump house control room.

Construction

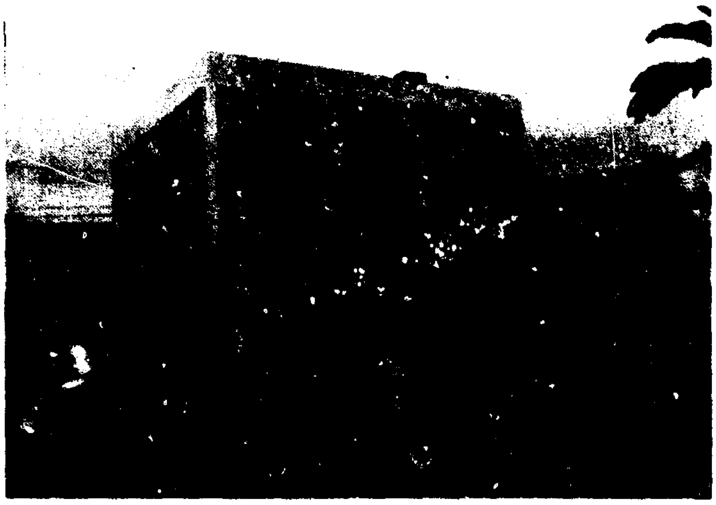
The construction and small size of the pump house offer very little fallout protection. The walls are primarily glass and aluminum with some concrete block. The roof is light sheet metal.

Protection

The control room section provides only a PF of 7.

BUILDING NO. 16

Long Beach Fire Alarm Building
Communications Center
1473 Peterson Street
Long Beach, California



Exterior View

Function

This facility receives all fire reports, both from alarm boxes and by telephone. Firemen and trucks of the various fire stations throughout the city are dispatched from this facility.

View of Interior Contents

Construction

The communications area is located on the south side of the second floor of a two-story building with masonry exterior walls and concrete floors. The rest of the second floor contains living quarters and the first floor is a shop area.

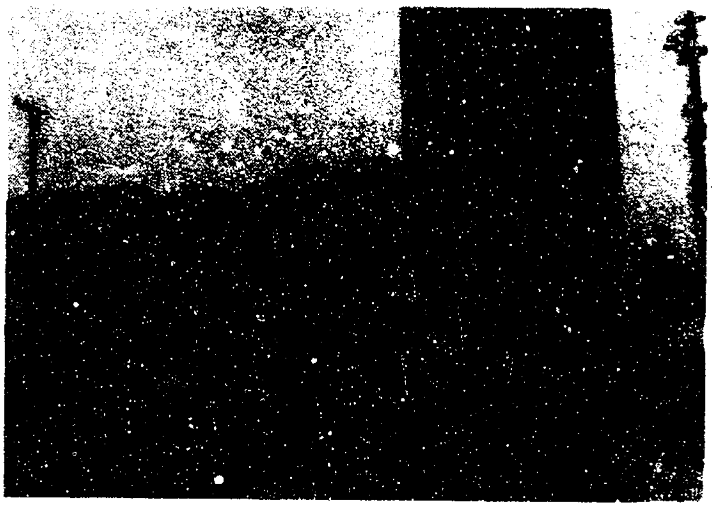
Protection

The PF of the area was calculated at 13 without interior contents and 16 with interior contents. Had the architect altered his design, it would have been possible to afford the operator minimum NFSS protection with very little additional expense. By utilizing the following changes, a PF of 52 could be obtained for an estimated cost of under $1,000 without destroying the aesthetics of the building.

1. Put aperture lower sill height at 4 feet and upper sill height at 7 feet,
2. Replace metal wall panels with masonry,
3. Relocate vehicle door to other side of building,
4. Cover front stair well, and
5. Increase roof thickness by four inches.

BUILDING NO. 17

Long Beach Community Hospital
1700 Termino Avenue
Long Beach, California



Exterior View

Function

This is one of the two large hospitals in Long Beach. The operating room, on the second story of the four story wing, was analyzed.

Construction

Community Hospital is constructed of 8 inch reinforced concrete walls and 6 inch reinforced concrete floors.

Protection

The Operating Room area of Community Hospital was found to have a PF of 45. This area was not included in the NFSS survey.

BUILDING NO. 18

General Telephone Company
of California
Downtown Long Beach Central
Office Building
550 Elm Avenue
Long Beach, California

Exterior View

<u>Function</u>

The Telephone Central Office Building contains the primary relay equipment for Long Beach. The trouble shooting board, located on the first story must be manned if malfunctions are to be spotted and corrected. The switch gear on the second story requires continued maintenance.

Trouble Shooting Board

<u>Construction</u>

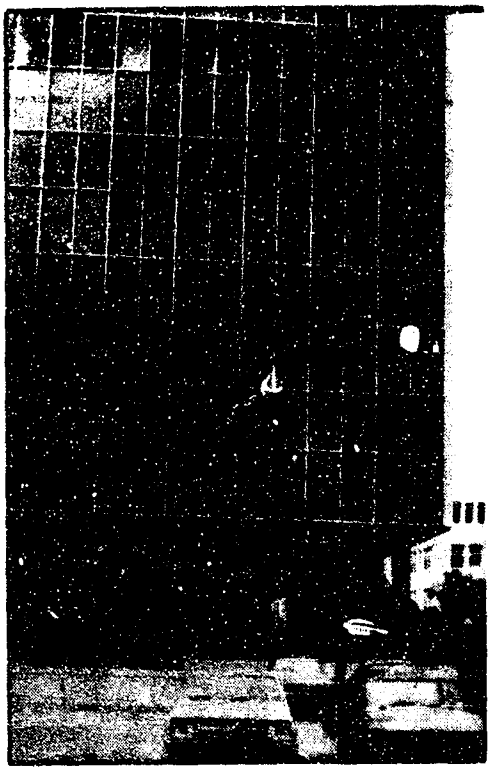
The Central Office Building is a four story structure of reinforced concrete.

<u>Protection</u>

The Trouble Shooting Board area (first story) has a PF of 312 with contents and and 223 without. The Switchgear area (second story) has a PF of 690 with contents and 81 without. The Long Distance Operator area (third story) has a PF of 80 with contents and 76 without. In this building, the interior contents increase the protection considerably.

BUILDING NO. 19

Police Communications Center
Public Safety Building
400 W. Broadway
Long Beach, California



Exterior View

Function

This facility is the nerve center of the Long Beach Police Department. All telephone calls are received here as well as all radio communications with patrol cars and motorcycles throughout the city.

Construction

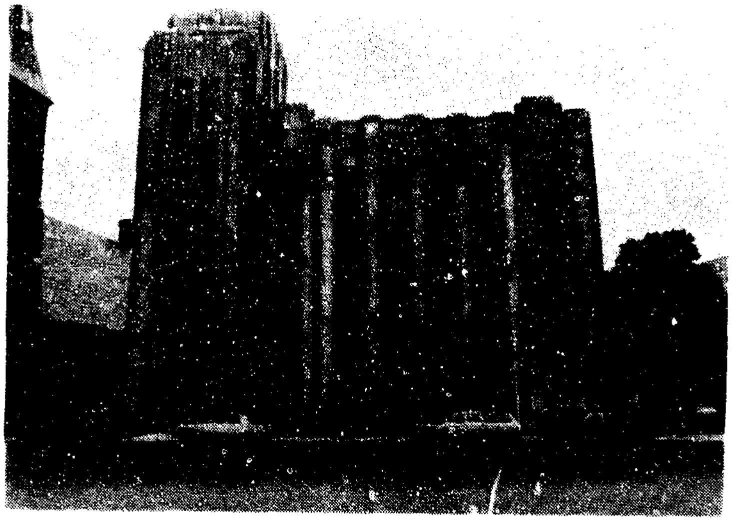
The Public Safety Building which contains the police communications center, is a modern six-story structure containing the police department, jail, and other municipal offices. The building is of curtain wall construction with the north and south walls of glass and metal; the east and west walls are of marble. The floors are concrete. The police communications center is in the southeast corner of the second floor.

Protection

Although the NFSS found basement and subbasement to be in PF Category 8, the upper stories did not reach PF Category 2. The area studied was found to have a PF of 32 and other areas closer to the center of the building would have higher PF's.

BUILDING NO. 20

New England Telephone Company
City Hall Square
Lynn, Massachusetts



Exterior View

Function

This facility houses the central telephone exchange for the city. Most of the equipment is automatic but maintenance personnel are required to be on each story at all times.

Construction

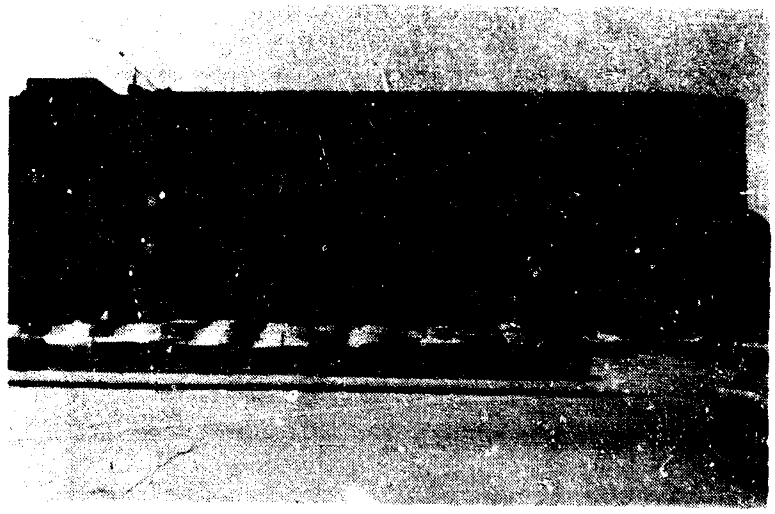
This structure has four stories and a basement. The building is of heavy concrete construction with limestone facing. Floors and roof are concrete.

Protection

The second story of this building, which contains relay racks, was analyzed and found to have a PF of 142. Interior contents were not considered as having any shielding effects due to the very light construction of the relay racks.

BUILDING NO. 21

Lynn Community Hospital
Lynn, Massachusetts



Exterior View

Function

This facility is the major hospital in the Lynn area and contains all of the usual hospital operations.

Construction

Construction of most of the entire hospital complex is concrete and steel frame with masonry exterior walls. The wing selected for analysis has 8" brick exterior walls with 3" concrete floors and roof. It has five stories and a basement.

Protection

The second story, which contains patient's rooms, was chosen for analysis and was found to have a PF of 22. The major contribution is through the apertures.

BUILDING NO. 22

Lynn Police Headquarters
Sutton Street
Lynn, Massachusetts

Exterior View

Function

This structure contains all city police offices, police communications center, and cell blocks. The communications center is manned at all times.

Construction

The portion of the building containing the communications center has brick faced tile walls, with 2" reinforced concrete floors and roof. The structure is two stories with a basement. The communications center is located on the first story near the front entrance to the building.

Protection

The PF in the first story area occupied by the operator was found to be 10.

BUILDING NO. 23

Fire Communications Center
Federal Avenue
Lynn, Massachusetts

Exterior View

Function

The second story of this facility houses the city-wide communications system for the fire department and is manned at all times. All incoming calls come to this location and are forwarded to the proper fire station.

Construction

This facility is a two-story light steel frame structure with masonry walls. The floors are of 3" lightweight concrete and the roof is tar and gravel over 2" lightweight concrete.

Protection

The PF in the second story of this building was found to be 6, due mainly to the light roof.

BUILDING NO. 24

Lynn Waterworks
Walnut Street
Lynn, Massachusetts

Exterior View

Function

This building contains pumps and valves necessary for distributing water throughout the city. It is necessary for the operator to be on the first story periodically for short periods of time (approximately 10 minutes out of each hour).

Construction

The building has heavy masonry walls with a wood-frame roof. The structure has one story and a basement. The first story floor is of wood joist construction except for one small area which has an 8" concrete floor.

Protection

Due to the relatively small size of the machinery contained in this building, no shielding effects were considered for internal contents. The operator's area was found to have a PF of 17. The basement area under the concrete portion of the floor would have a PF considerably higher than the first story and would provide protection to the operator except for the periodic trips to the first story.

BUILDING NO. 25

Massachusetts Gas and Electric Company
Lynn Station - Boiler House
Broad Street
Lynn, Massachusetts

Exterior View

Function

This facility houses the boilers and power generating equipment. The boilers are located on the second story and the boiler operators must be in essentially full-time attendance in order to maintain the boilers.

Construction

The facility is a two-story building of heavy masonry construction. The floor of the second story is 6" reinforced concrete.

Protection

The boiler operator's area was found to have a PF of 16. This includes the shielding effects of the boilers. If shielding by the boilers is neglected, the PF is 13.

BUILDING NO. 26

Massachusetts Gas and Electric Company
Lynn Station - Control Room
Broad Street
Lynn, Massachusetts

Exterior View

Function

This building contains the switchboards, circuit breakers, and related equipment used in the distribution of electric power. Outdated turbines and generating equipment are also located here but they are no longer in use.

Construction

The structure is basically one tall story of heavy masonry construction. The switching equipment is enclosed in a small cubicle on one side of the building. This enclosure has an upper story where all operations are carried out. The floor of the upper story is 6" of concrete. The entire building roof is slate with 1/4" gypsum backing.

Protection

The PF in the operator's station was found to be 14. The generating equipment located in this building offers no shielding effects due to its location relative to the operator's area.

Appendix D

Description of Key Facility PF Computer Program

This appendix contains the following data which are necessary to define the computer program for determining the protection factors in key facilities, or other irregularly constructed buildings:

TAB 1 Building Data for PF Processing

TAB 2 Sector Data for PF Processing

TAB 3 Table of GAT Variables

TAB 4 Flow Charts for Key Facility PF Computer Program

TAB 5 Sample Printout

TAB 6 Table of Output Variables

Data inputs indicated in Tabs 1 and 2 are given to the nearest foot for dimensions and to the nearest psf for mass thicknesses.

TAB 1

BUILDING DATA FOR PF PROCESSING

________	(Standard Location, xxxx.xxxx)
________	(Facility Number (4 digits) and Part of Parts, xxxx.xxxx)
________	(Total Height)
________	(Height of Story 0)
________	(" 1)
________	(" 2)
________	(" 3)
________	(" 4)
________	(" 5)
________	(" 6)
________	(" 7)
________	(" 8)
________	(" 9)
________	(" 10)
________	(Floor Weight (psf) of Story 0)
________	(" 1)
________	(" 2)
________	(" 3)
________	(" 4)
________	(" 5)
________	(" 6)
________	(" 7)
________	(" 8)
________	(" 9)
________	(" 10)
________	(Roof psf)
________	(No. of Stories)
________	(Number of Sectors in Building)

TAB 2

SECTOR DATA FOR PF PROCESSING

________	Facility Number (4 digits) and Part of Parts, xxxx.xxxx	
________	Sector Number	
________	Az, Degrees in Sector	
________	Lz, Length of Wall in Sector	
________	Width of Building	
________	Length of Building	
________	S, Side of Building Containing Sector	
________	Re, Radius out to midpoint of Sector Wall	
________	Height of 1st plane	
________	Height of 2nd plane	
________	Height of 3rd plane	
________	Width of 1st plane	
________	Width of 2nd plane	
________	Width of 3rd plane	
________	Actual Height of First Plane if it is Water	
________	Xe(Exterior Wall Mass Thickness)	Story 0
________	Xi(Interior Partition Mass Thickness)	
________	Aza(Degrees of Apertures in Sector)	
________	L.S.Ht.(Lower Sill Height)	
________	U.S.Ht.(Upper Sill Height)	
________	W. of Ap.(Width of Apertures	
________	Xe	Story 1
________	Xi	
________	Aza	
________	L.S.Ht.	
________	U.S.Ht.	
________	W. of Ap.	
________	Xe	Story 2
________	Xi	
________	Aza	
________	L.S.Ht.	
________	U.S.Ht.	
________	W. of Ap.	
________	Xe	Story 3
________	Xi	
________	Aza	
________	L.S.Ht.	
________	U.S.Ht.	
________	W. of Ap.	
________	Xe	Story 4
________	Xi	
________	Aza	
________	L.S.Ht.	
________	U.S.Ht.	
________	W.of Ap.	
________	Xe	Story 5
________	Xi	
________	Aza	
________	L.S.Ht.	
________	U.S.Ht.	
________	W. of Ap.	
________	Xe	Story 6
________	Xi	
________	Aza	
________	L.S.Ht.	
________	U.S.Ht.	
________	W. of Ap.	

TAB 1

BUILDING DATA FOR PF PROCESSING

__________ (Standard Location, xxxx.xxxx)
__________ (Facility Number (4 digits) and Part of Parts, xxxx.xxxx)
__________ (Total Height)
__________ (Height of Story 0)
__________ (" 1)
__________ (" 2)
__________ (" 3)
__________ (" 4)
__________ (" 5)
__________ (" 6)
__________ (" 7)
__________ (" 8)
__________ (" 9)
__________ (" 10)
__________ (Floor Weight (psf) of Story 0)
__________ (" 1)
__________ (" 2)
__________ (" 3)
__________ (" 4)
__________ (" 5)
__________ (" 6)
__________ (" 7)
__________ (" 8)
__________ (" 9)
__________ (" 10)
__________ (Roof psf)
__________ (No. of Stories)
__________ (Number of Sectors in Building)

[illegible]

Table of [illegible] Variables

INPUT VARIABLES

Z8	Aperture percentage for story above
Z10	Distance from detector to wall
Z11	Height (floor to ceiling) of story below
Z12	Height (floor to ceiling) of detector story
Z13	Lower sill height of aperture
Z14	Height of detector above floor
Z15	Height of upper sill of aperture
Z16	Distance from detector to detector story ceiling
Z17	Distance from detector to ceiling of story above
Z18, Z19, Z20	Height of contaminated planes 1, 2, and 3
Z21, Z22, Z23	Width of contaminated planes 1, 2, and 3
Z36	Average height of upper stories of building
Z37	Average lower sill height above detector story floor
Z38	Average upper sill height above detector story floor
Z42	Aperture percentage for basement
Z44	Height (floor to ceiling) of basement
Z45, Z46, Z47, Z48, Z49	Height (floor to ceiling) of first five stories respectively
Z0, Z9, Z24-Z35, Z39-Z41, Z43, Z50-Z60	are all primary or secondary temporary storages for use in setting up radiation factors. Also, except for initialization, Z36-Z38 and Z44-Z50 are used for primary or secondary temporary storages.

CONTRIBUTION VARIABLES

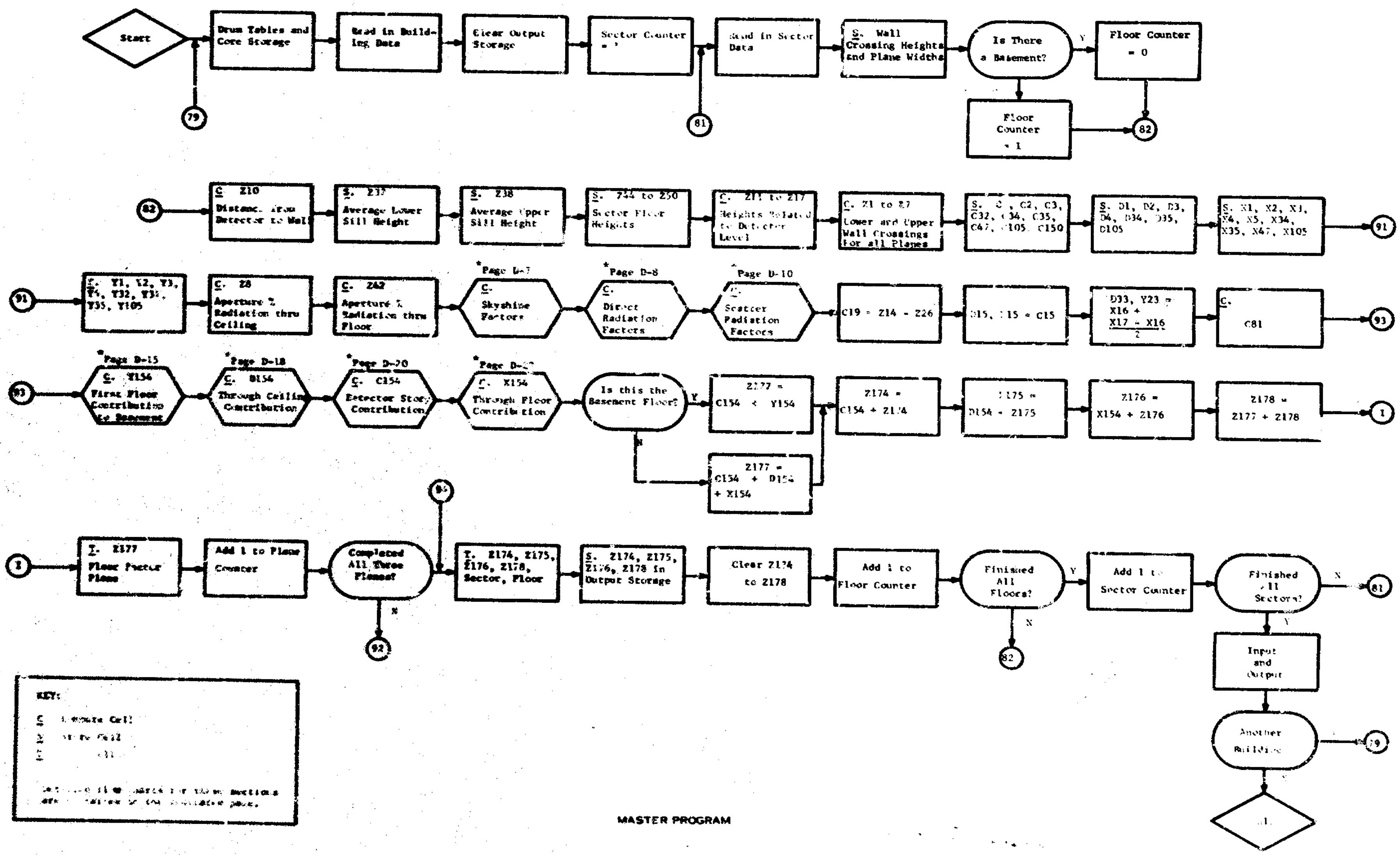
C1 (D1 = X1 = Y1)	Number of degrees in sector (A_s)
C2 (D2 = X2 = Y2)	Exterior wall psf (X_e)
C3 (D3 = X3 = Y3)	Interior partition psf (X_i)
D4 (Y4)	Ceiling psf (X_o')
X4	Floor psf (X_f)
D5 (X5)	Length of wall in sector (L_s)
C15 (D15 = X15)	Height of detector above plane of contamination (H)
X16	Percentage of apertures for direct contribution
X17	(1 - X16)
D18 (X18)	Percentage of apertures for scatter contribution
D19 (X19)	(1 - D18) (1 - X19)
X20	Distance to midwall of story below detector story
D21	Percentage of apertures for skyshine contribution
D22	(1 - D21)
D23 (Y23)	Distance to midwall of story above detector story
C24 (D24 = X24 = Y24)	B_w (C2, C15)
C25 (D25 = X25 = Y25)	B_w (C3, 3')
C26 (D26 = X26)	B_w (0, C15)
D27 (X27 = Y27)	B_o' (D4) or B_o (X4)
C28 (D28 = X28 = Y28)	E_w (C2)
C29 (D29 = X29 = Y29)	1 - E_w (C2)
D30 (X30 = Y30)	D1 · D25 · D27
C31	C1 · C24 · C25
C32 (Y32)	Number of degrees of apertures in sector
C33 (Y33)	Perimeter of apertures in sector
C34 (D34 = X34 = Y34)	Width of building
C35 (D35 = X35 = Y35)	Length of building
D36 (Y36)	Code for skyshine
C37 (D37 = Y37)	Distance to ceiling of detector story
C38 (D38 = Y38)	Distance to mutual shield
C39 (D39 = Y39)	2 · C37/C35
C40 (D40 = Y40)	2 · C38/C35
C41 (D41 = X41 = Y41)	C34/C35
C42 (D42 = Y42)	ω(C39, C41)
C43 (D43 = Y43)	ω(C40, C41)
C44 (D44 = Y44)	G_s (C42)
C45 (D45 = Y45)	G_s (C43)
C46 (D46 = Y46)	C44 - C45
C47 (X47)	Radius to midwall (R_f)
C48 (X48)	Height of detector to wall crossing (direct-inner)
C49 (X49)	Height of detector to wall crossing (direct-outer)
C50 (X50)	C47/C48
C51 (X51)	C47/C49
C52 (X52)	1 - (C50)^2
C53 (X53)	1 - (C51)^2
C54 (X54)	1 / (C52)^{½}
C55 (X55)	1 / (C53)^{½}
C56 (X56)	1 - C54
C57 (X57)	1 - C55
C58 (X58)	G_d (C56, C15)
C59 (X59)	G_d (C57, C15)
C60 (X60)	C59 - C58
Y61	Code for aperture skyshine shielding
C62 (Y62)	Distance to top of window above detector
C63 (Y63)	Distance to lower sill above detector (or 0)
C64 (Y64)	2 · C62/C35
C65 (Y65)	2 · C63/C35
C66 (Y66)	ω(C64, C61)
C67 (Y67)	ω(C65, C61)
C68 (Y68)	G_s (C66)

CONTRIBUTION VARIABLES (CONT'D)

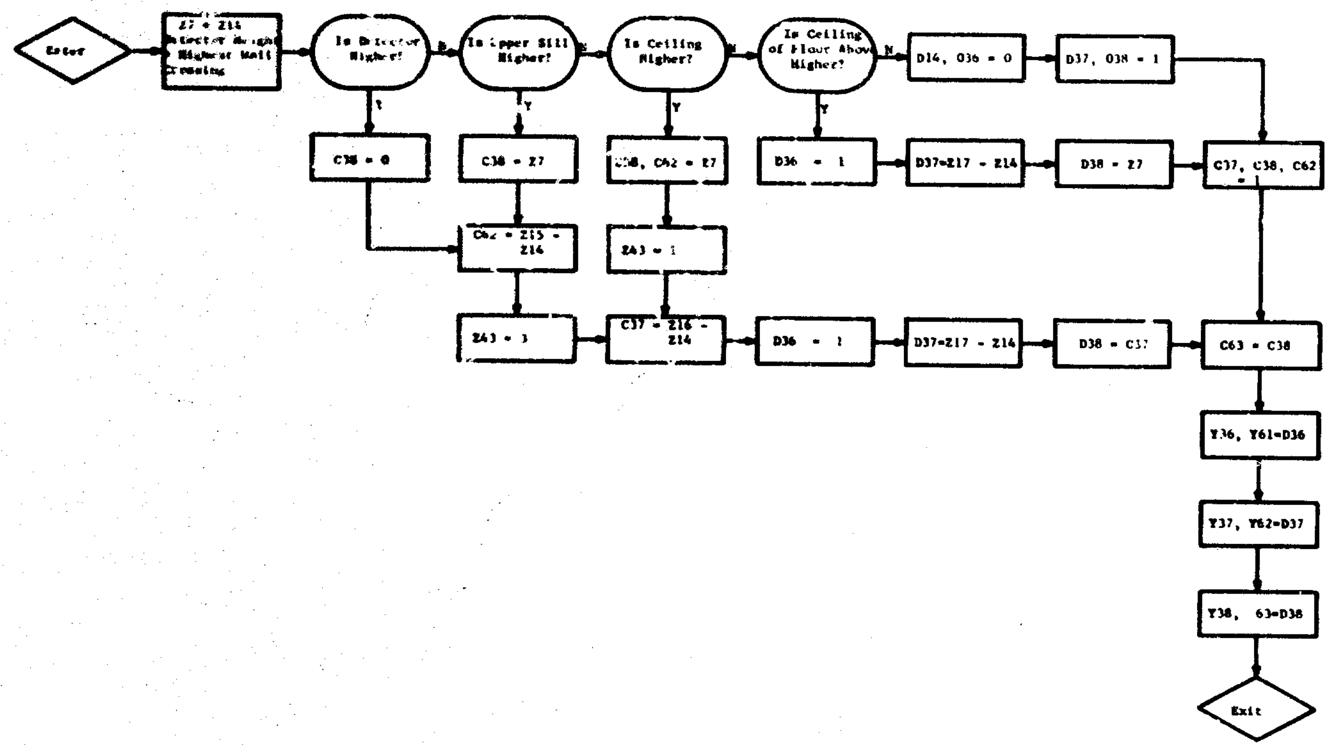
C69 (Y69)	G_s (C67)
C70 (Y70)	C68 - C69
Y71	Code for wall scatter on apertures
C72 (Y72)	Distance to top of window from detector
C73 (Y73)	Distance to bottom of window from detector
C74 (Y74)	2 · C72/C35
C75 (Y75)	2 · C73/C35
C76 (Y76)	ω(C74, C41)
C77 (Y77)	ω(C75, C41)
C78 (Y78)	G_s (C76)
C79 (Y79)	G_s (C77)
C80 (Y80)	C78 - C79 or C78 + C79
C81 (X81)	Height of detector above floor (3')
X82	Distance from detector to floor of story below
C83 (X83)	2 · C81/C35
X84	2 · X82/C35
C85 (X85)	ω(C83, C41)
X86	ω(C84, C41)
C87 (X87)	G_s (C85), G_s (X85)
X88	G_s (X86)
X89	X88 - X87
D90 (Y90)	Code for wall scatter
C91 (D91 = Y91)	Distance to ceiling from detector
D92 (Y92)	Distance to floor from detector
C93 (D93 = Y93)	2 · C91/C35
D94 (Y94)	2 · D92/C35
C95 (D95 = Y95)	ω(C93, C41)
D96 (Y96)	ω(D94, C41)
C97 (D97 = Y97)	G_s (C95), G_s (D95)
D98 (Y98)	G_s (D96)
D99 (Y99)	D97 - D98
C100	C87 + C97
C102 (D102 = X102 = Y102)	Distance from midwall to contaminated plane
C103 (D103 = X103 = Y103)	Distance to beginning of plane
C104 (D104 = X104 = Y104)	Distance to end of plane
C105 (D105 = X105 = Y105)	Building length adjacent to sector
C106 (D106 = X106 = Y106)	2 · C103
C107 (D107 = X107 = Y107)	2 · C104
C108 (D108 = X108 = Y108)	C106 + C105
C109 (D109 = X109 = Y109)	C107 + C105
C110 (D110 = X110 = Y110)	C106/C108
C111 (D111 = X111 = Y111)	C107/C109
C112 (D112 = X112 = Y112)	2 · C102/C108
C113 (D113 = X113 = Y113)	2 · C102/C109
C114 (D114 = X114 = Y114)	ω(C110, C112)
C115 (D115 = X115 = Y115)	ω(C111, C113)
C116 (D116 = X116 = Y116)	½ C114
C117 (D117 = X117 = Y117)	½ C115
C118 (D118 = X118 = Y118)	B_{ws} (C116, C2)
C119 (D119 = X119 = Y119)	B_{ws} (C117, C2)
C120 (D120 = X120 = Y120)	C118 - C119
C121 (D121 = X121 = Y121)	E(C41)
C122 (Y122)	C33 · C70
C123 (Y123)	C46 - C122
C124 (D124)	C123 + C60
C125 (D125 = X125 = Y125)	C124 · C29
Y126	Y33 · Y80
Y127	Y99 - Y126
C128 (D128 = X128 = Y128)	C121 · C120 · C100 · C28/C24
C129 (D129 = Y129)	C125 + C128 (Y125 + Y128 + Y127)
C130	C129 · C31
C131	C70 · C26
C132	C28 · C80 · C120 · C121
C133	C131 - C132
C134 (X134)	C133 · C25 · C32
C135 (X135)	C130 + C134 (X134 + X128 + X125)
C136	C47
C137	Upper limit of direct through aperture
C138	Lower limit of direct through aperture
C139	C137/C136
C140	C137/C136
C141	1 + (C139)^2
C142	1 + (C140)^2
C143	1/(C141)^{½}
C144	1/(C142)^{½}
C145	1 - C143
C146	1 - C144
C147	G_d (C145, C15)
C148	G_d (C146, C15)
C149	C148 - C147
C150	Degrees of aperture for direct = C32
C151	C25 · C149 · C150
C152	C150 · C140 · C20 · C31/C1
C153 (D153 = X153 = Y153)	Sum of all sub-totals
C154 (D154 = X154 = Y154)	Reduction factor for this plane (C153/360)

TAB 4

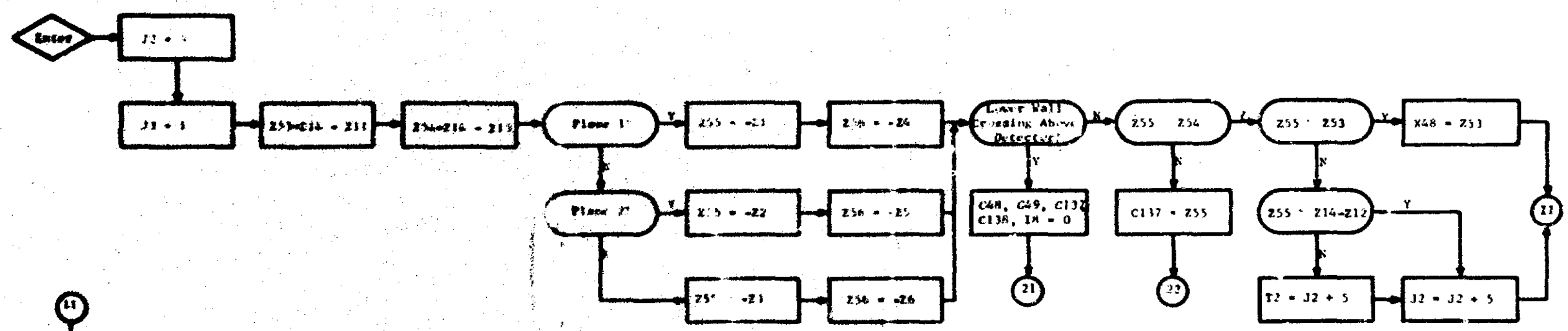
Flow Charts for Key Facility
PF Computer Program

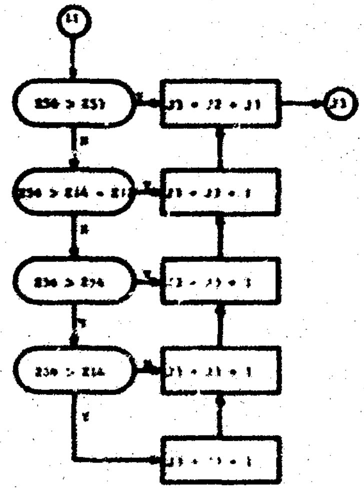


MASTER PROGRAM



SKYSHINE FACTORS SETUP

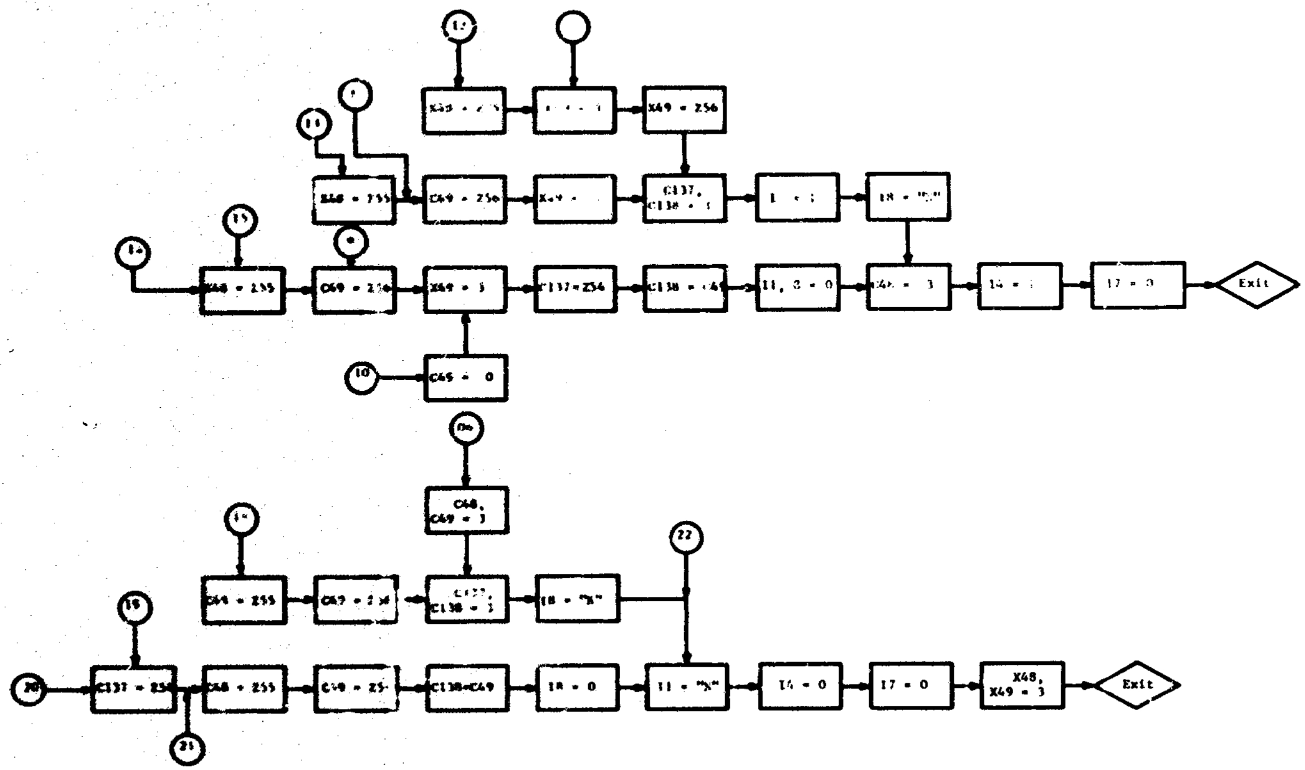




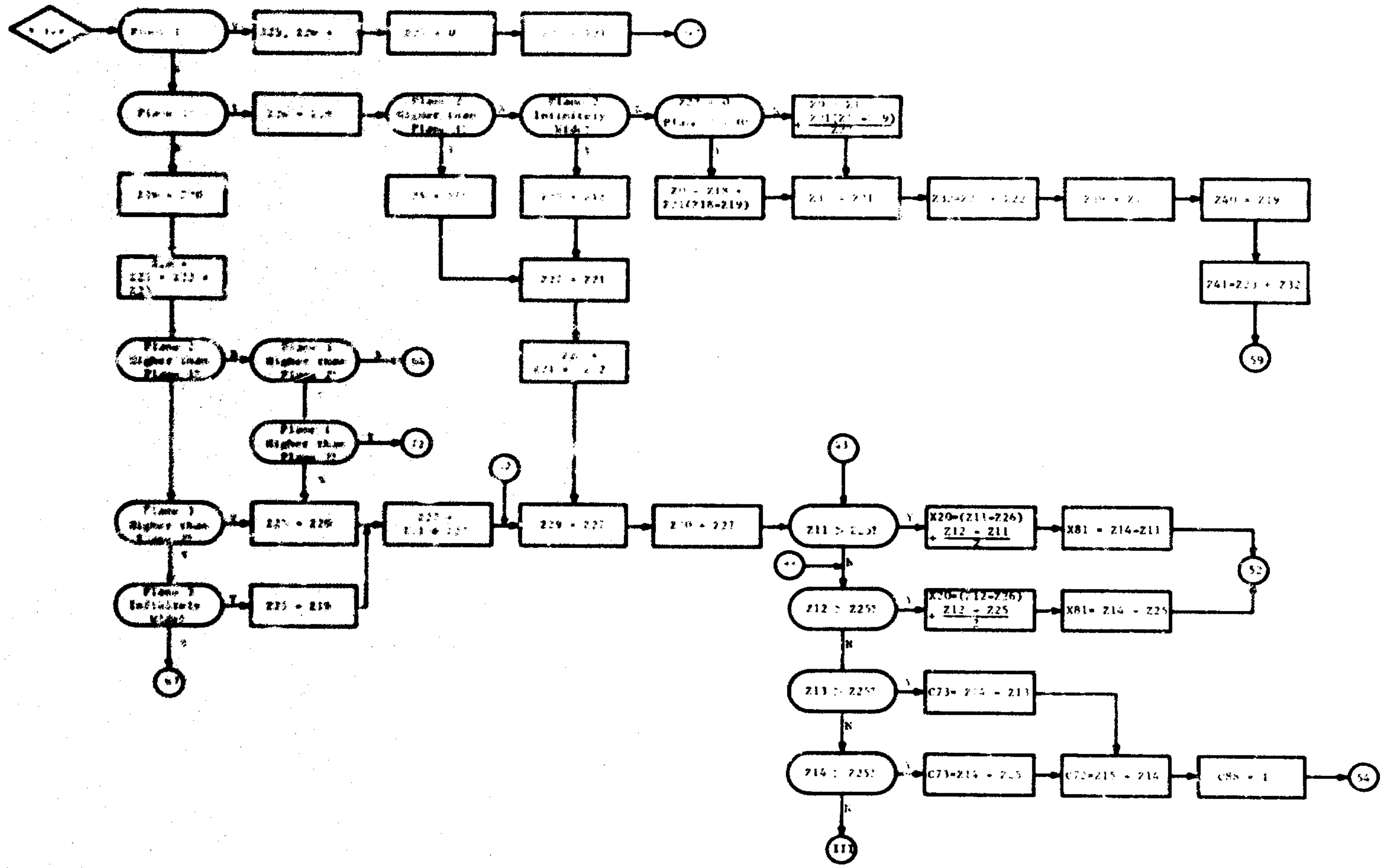
POSSIBLE VALUES OF J3

Upper Wall Crossing	Lower Wall Crossing ≤ Z11	> Z11	> Z12	> Z13
≤ Z11	06	-----	-----	-----
> Z11	07	12	-----	-----
> Z12	08	13	18	-----
> Z13	09	14	19	-----
> Z14	10	15	20	-----

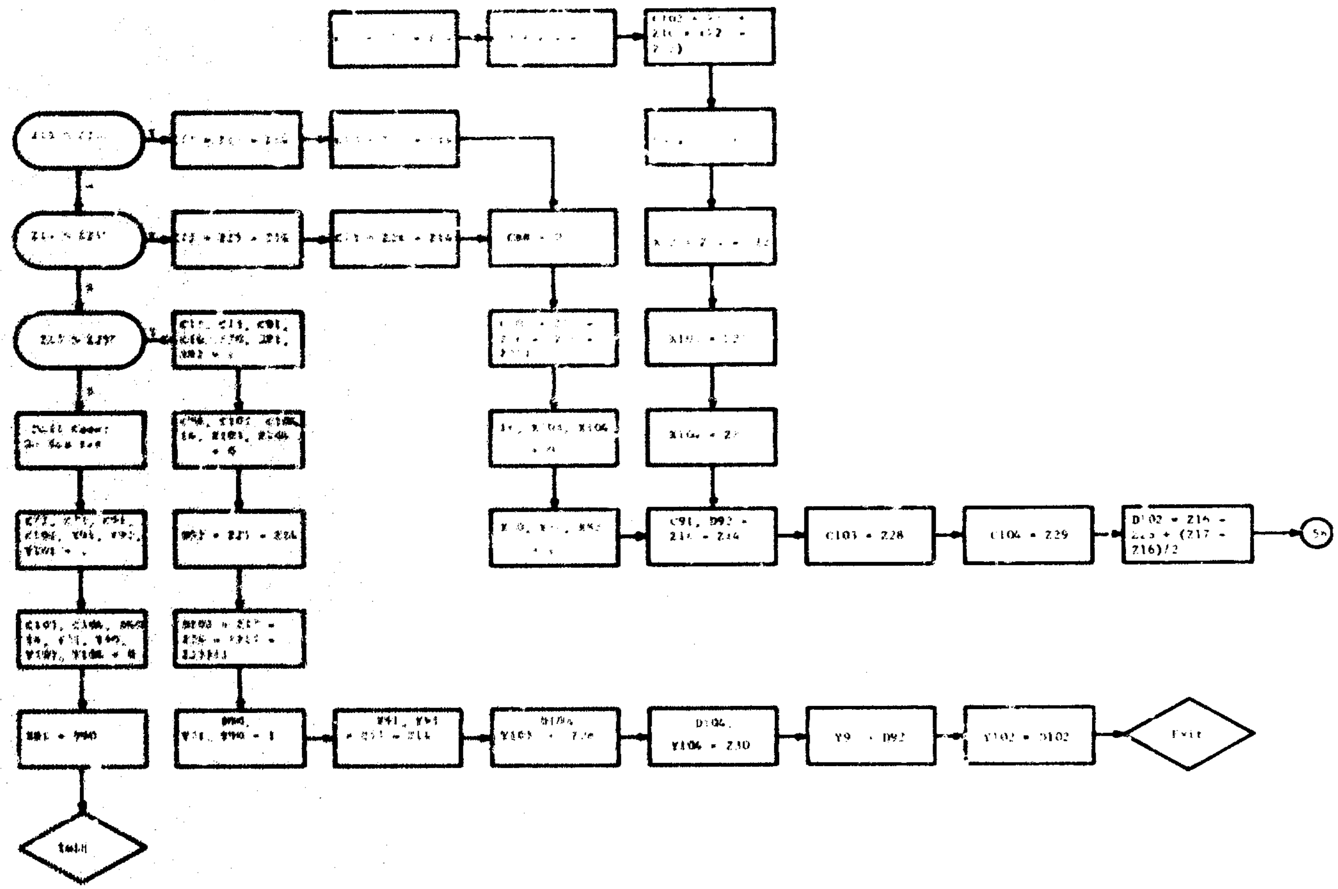
DIRECT RADIATION FACTORS SETUP



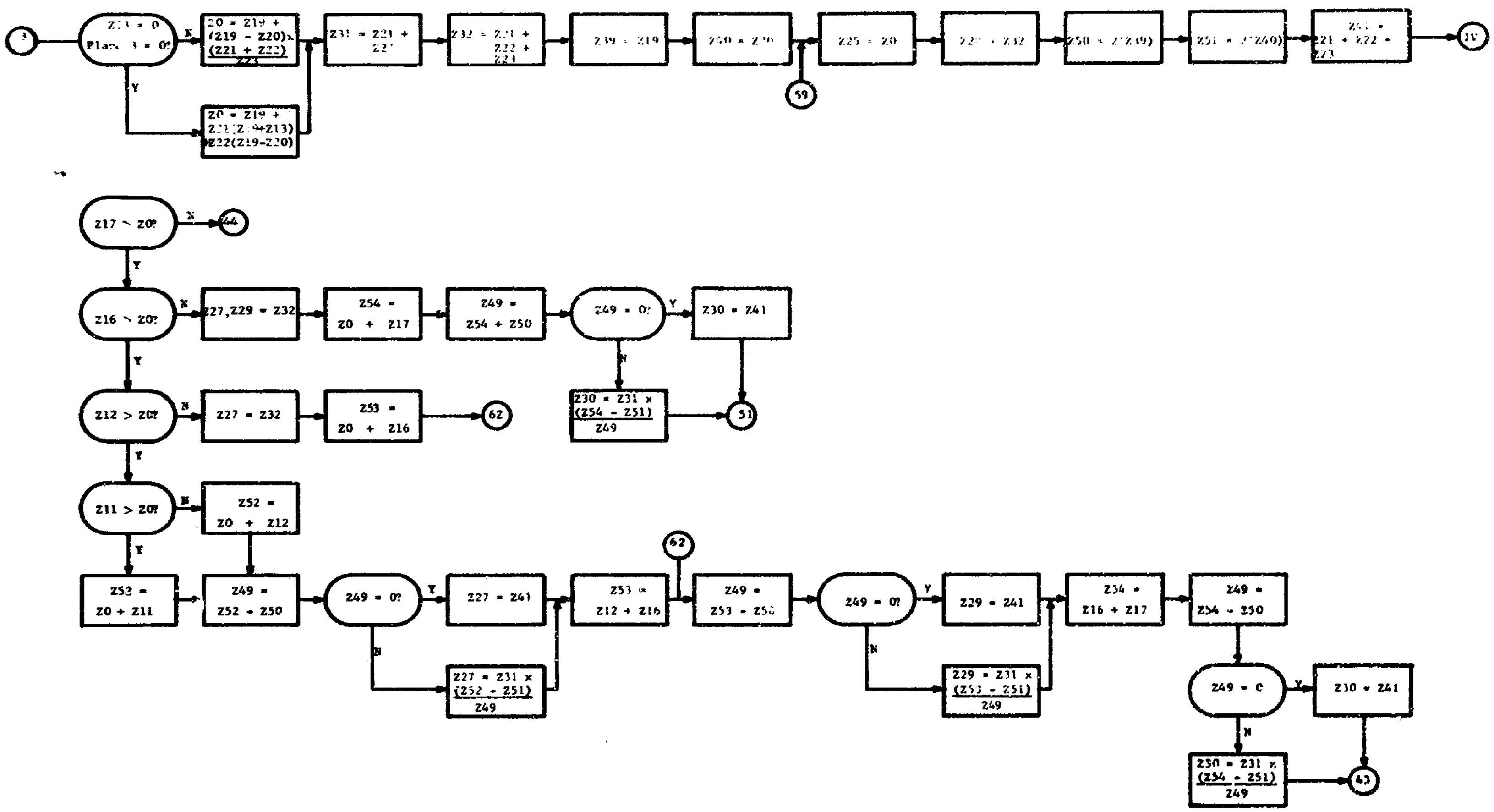
DIRECT RADIATION FACTORS SETUP (CONT'D.)



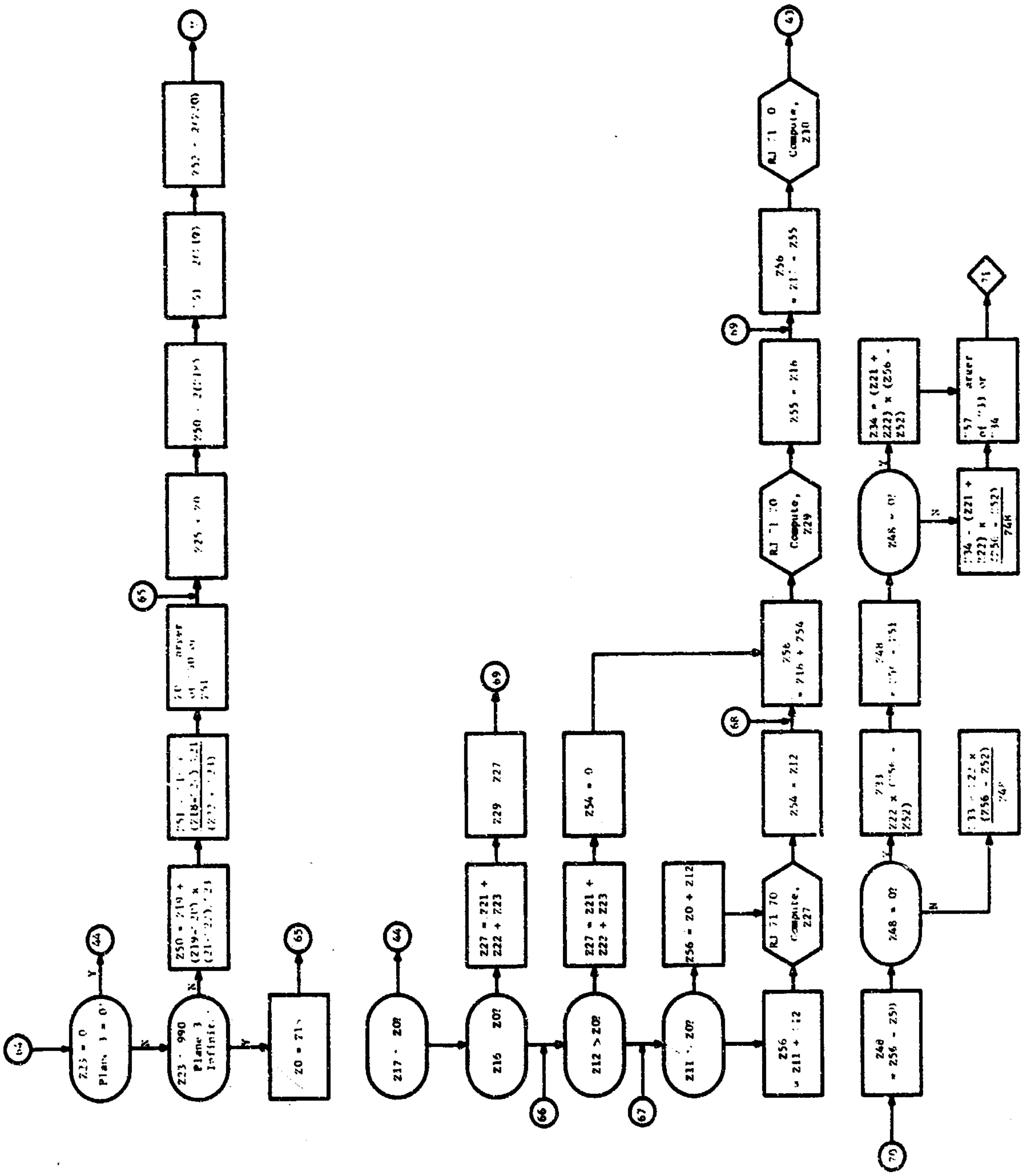
SCATTER RADIATION FACTOR SETUP



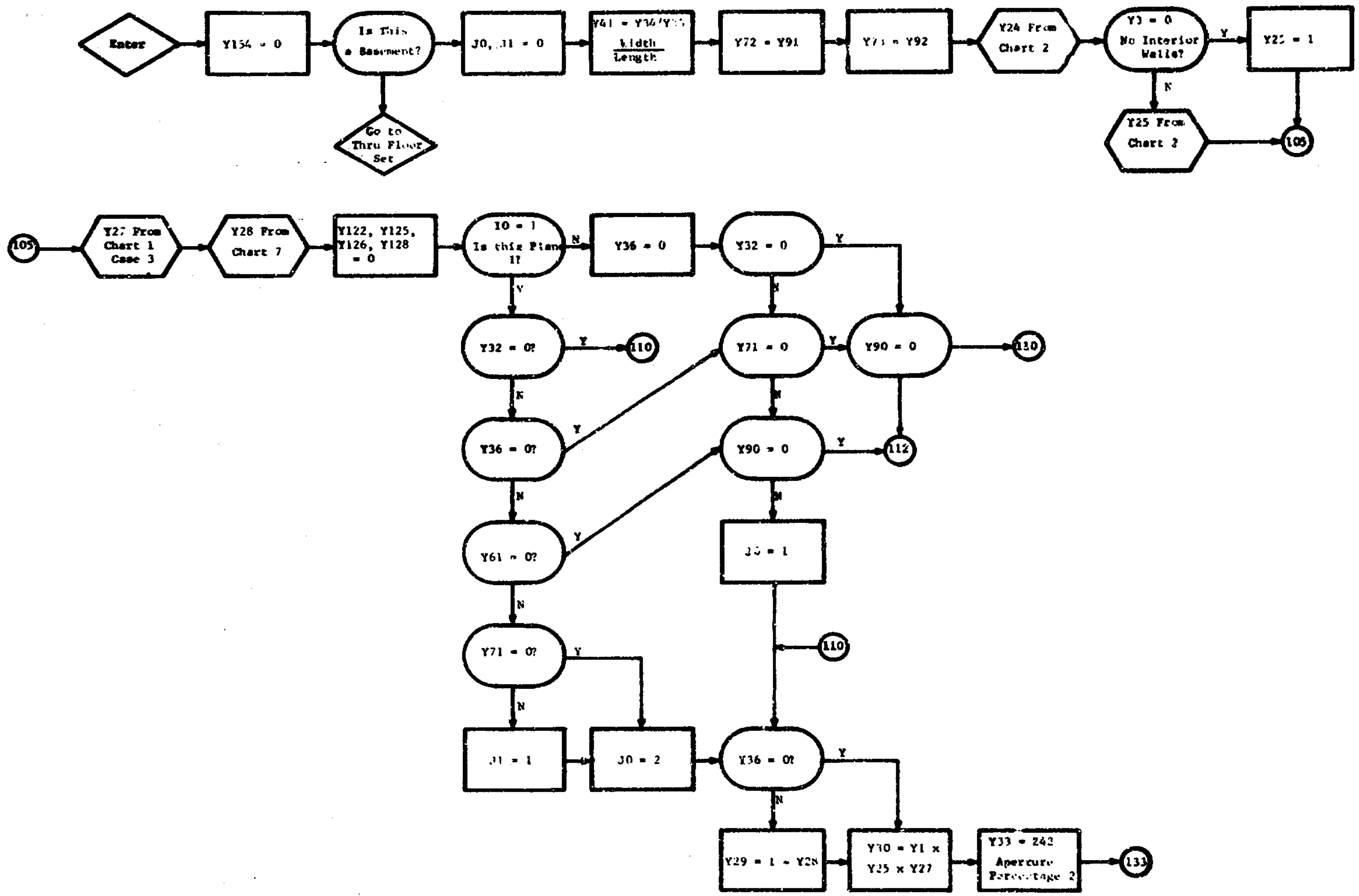
SCATTER RADIATION FACTORS SETUP (CONT'D.)



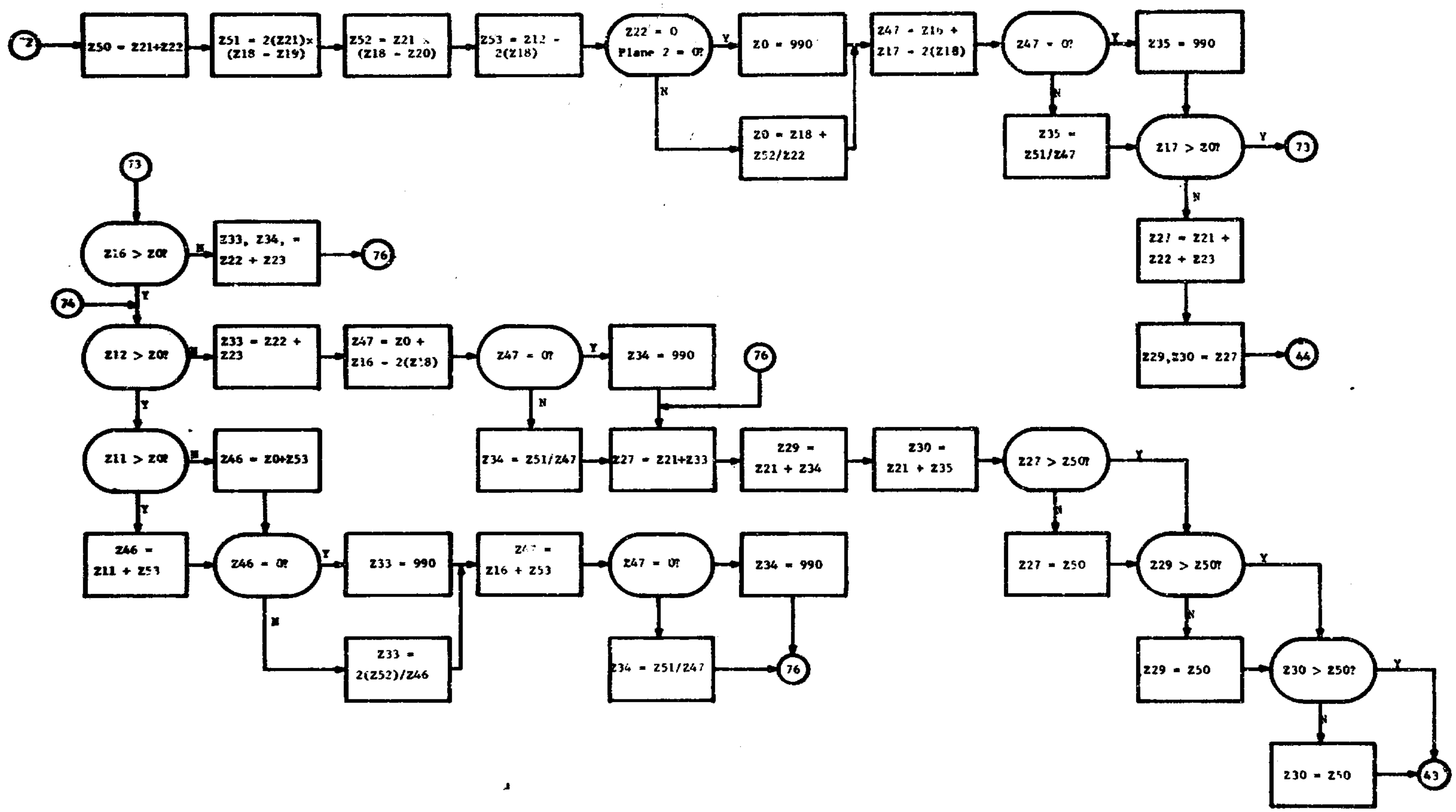
SCATTER RADIATION FACTORS SETUP (CONT'D.)



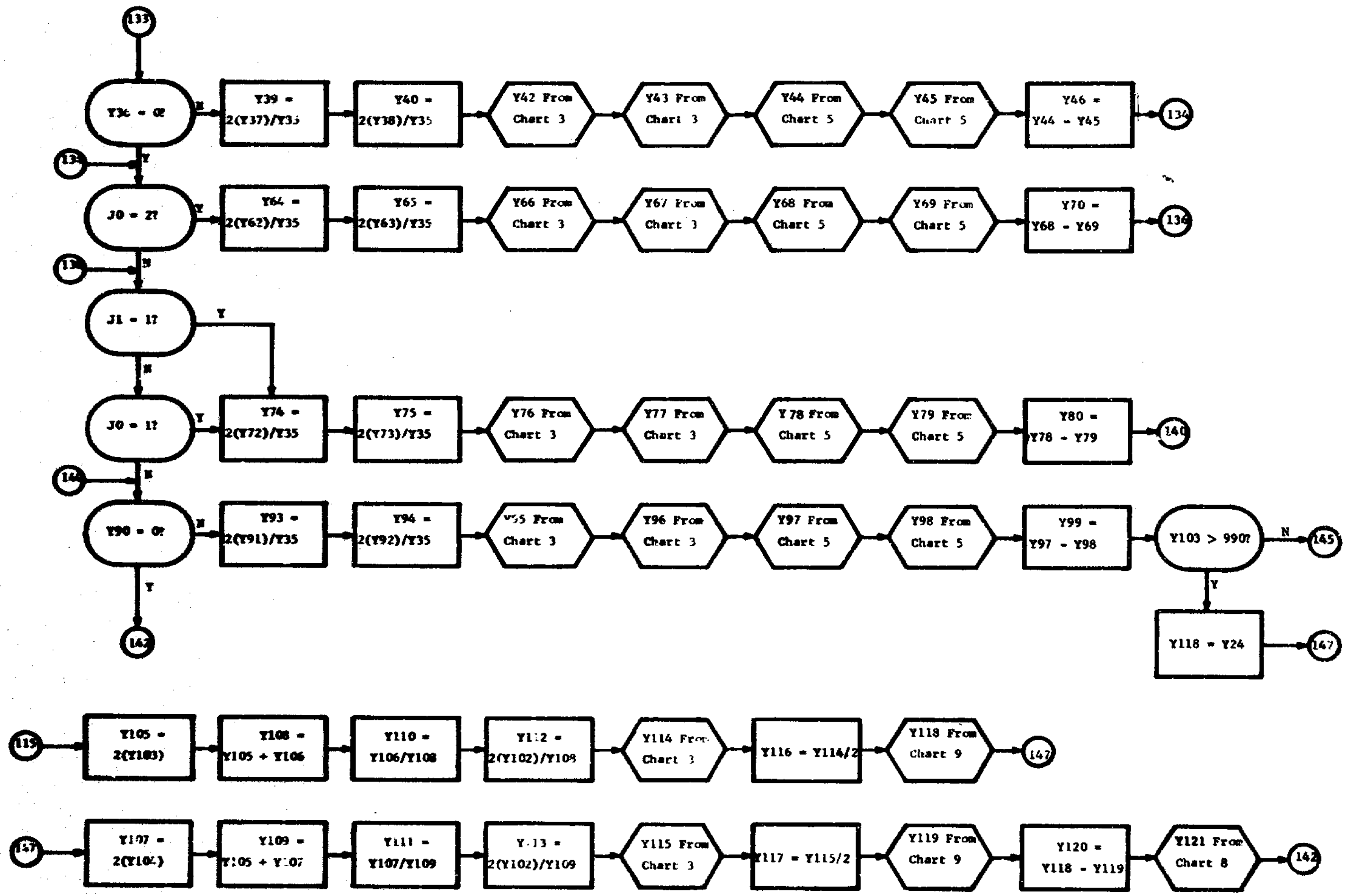
SCATTER RADIATION FACTORS SETUP (CONT'D)



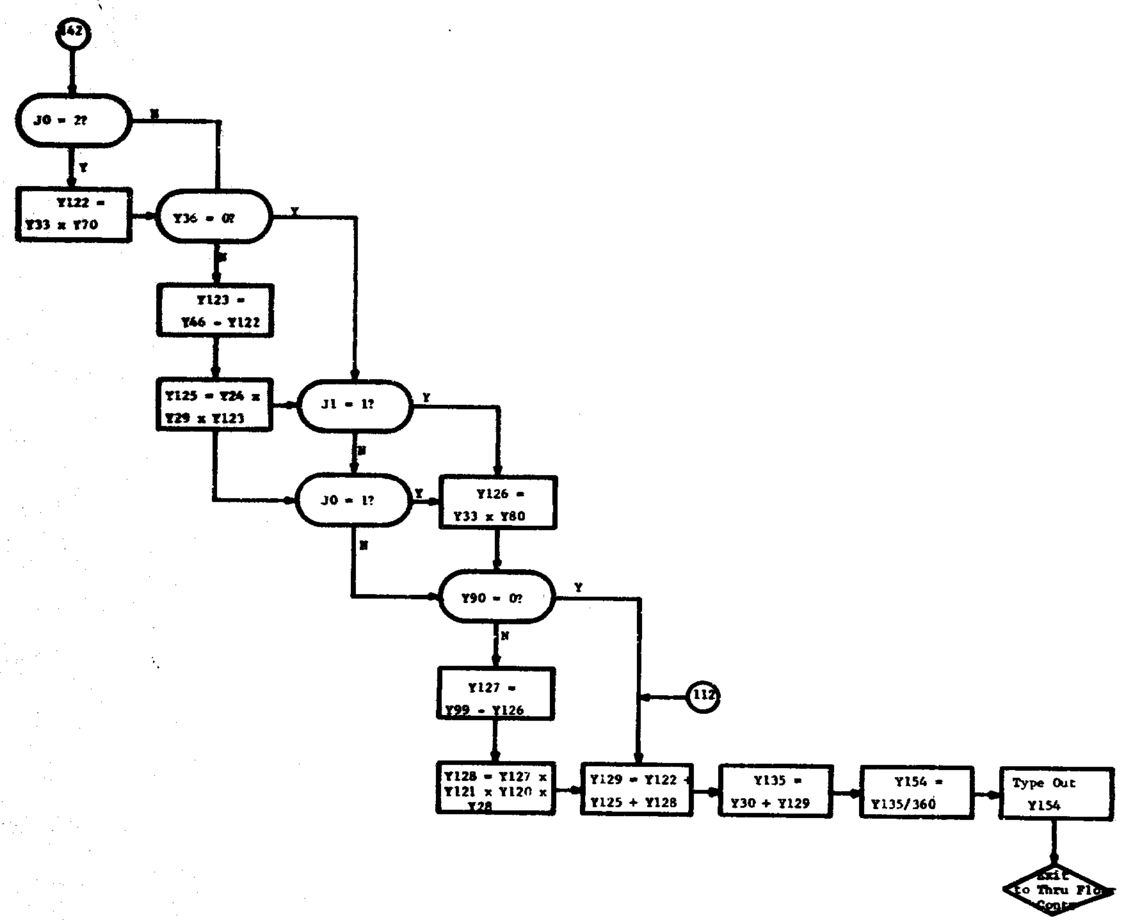
SCATTER RADIATION FACTORS SETUP (CONT'D.)



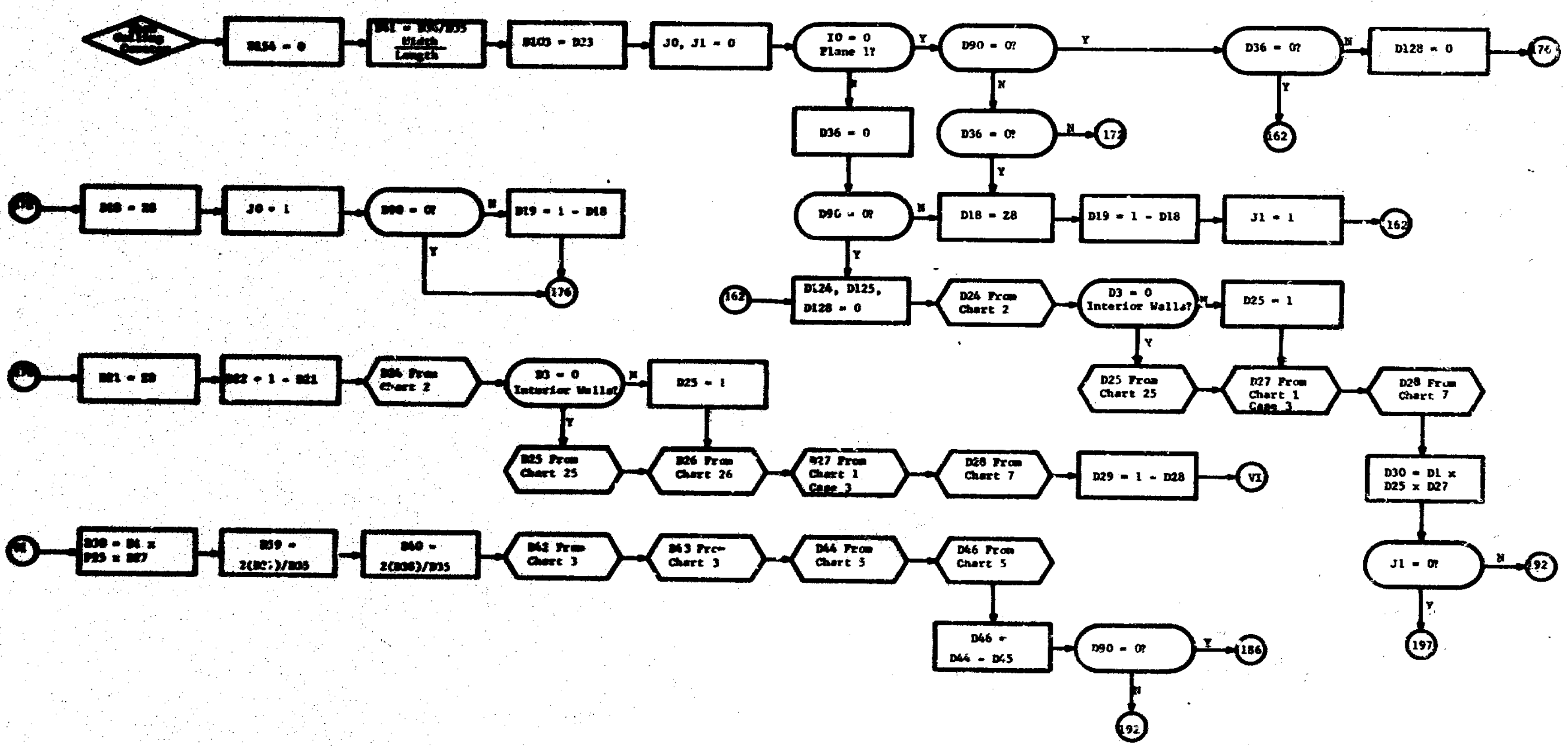
FIRST FLOOR CONTRIBUTION TO BASEMENT



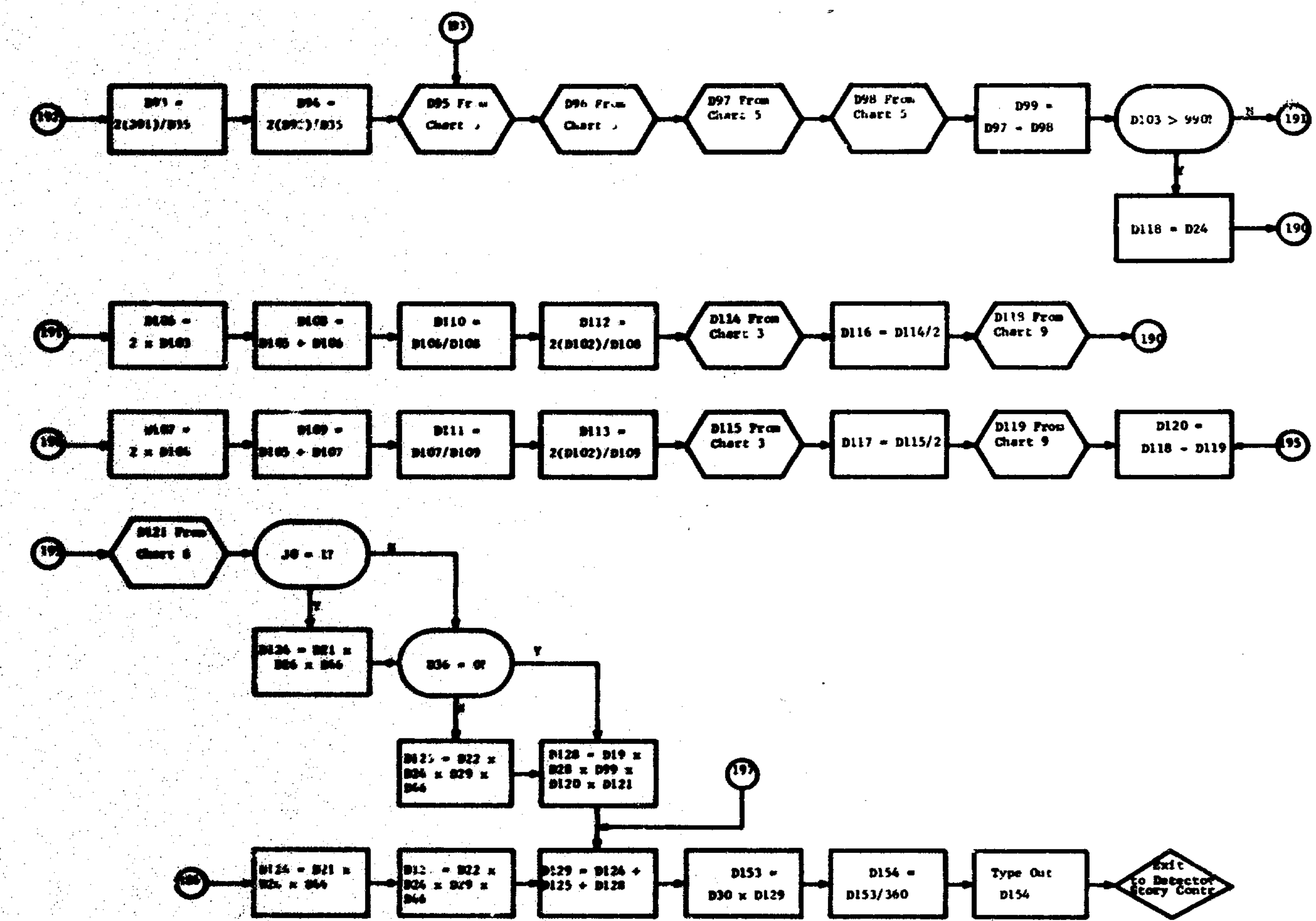
FIRST FLOOR CONTRIBUTION TO BASEMENT (CONT'D.)



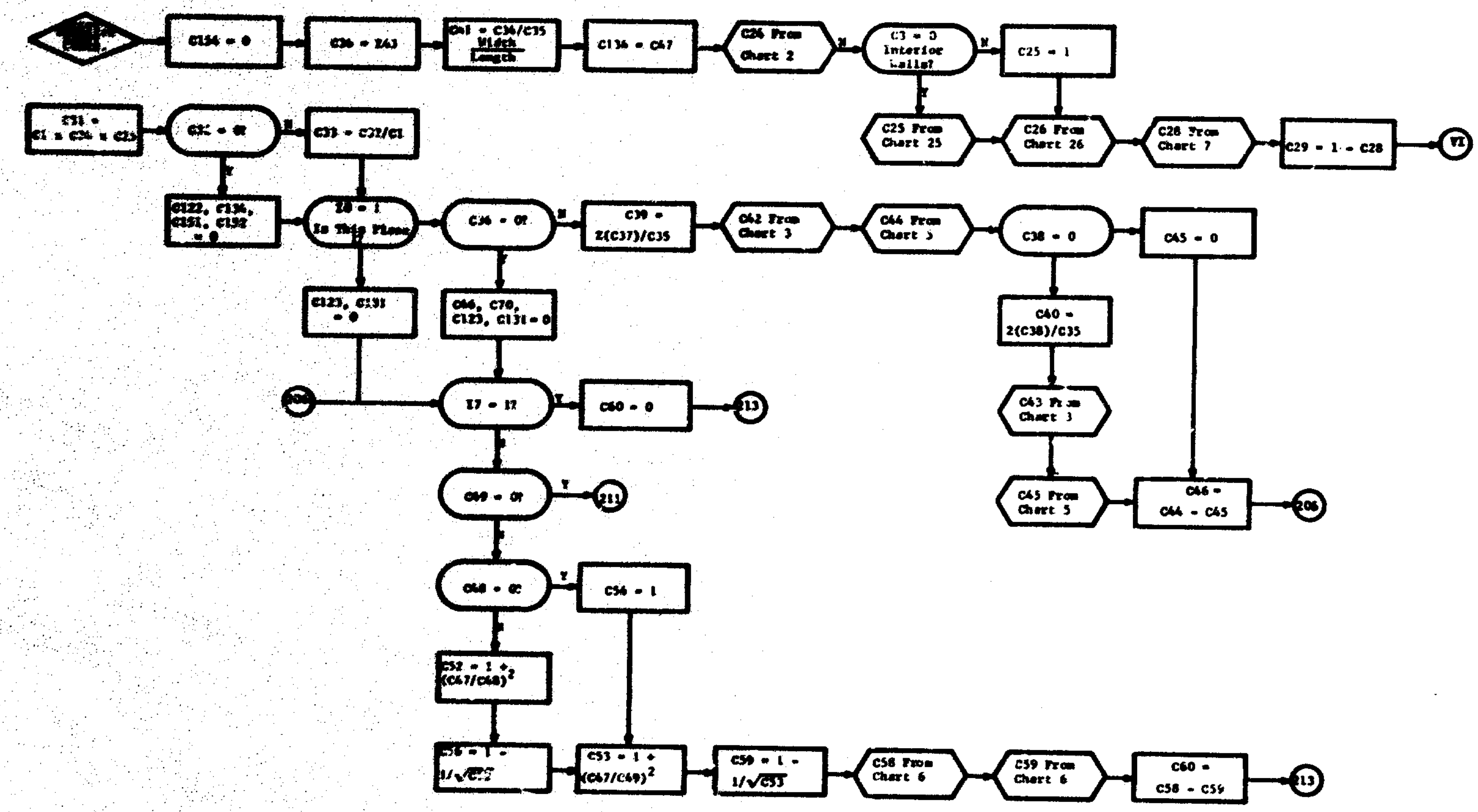
FIRST FLOOR CONTRIBUTION TO BASEMENT (CONT'D.)



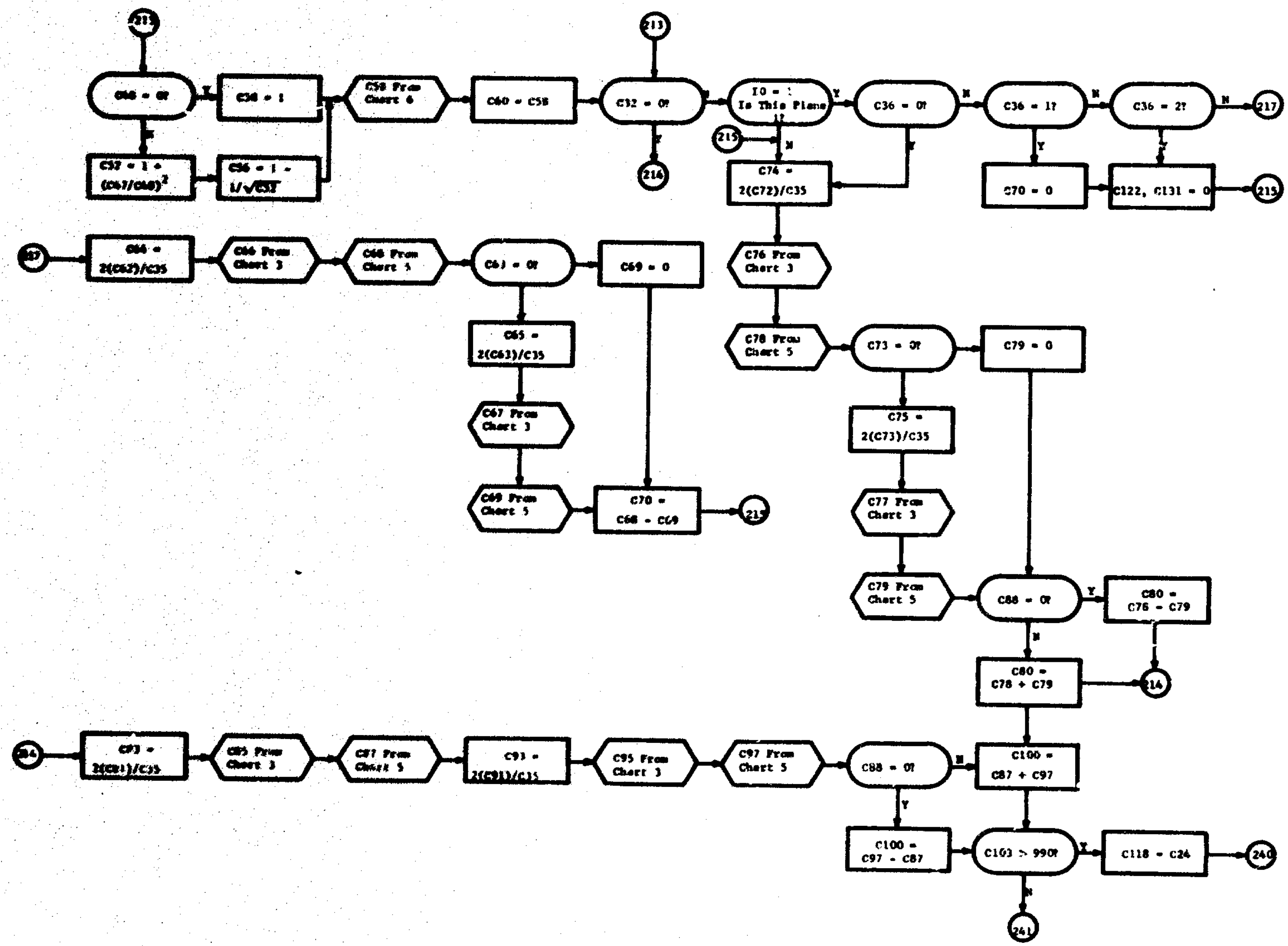
THROUGH CEILING CONTRIBUTION



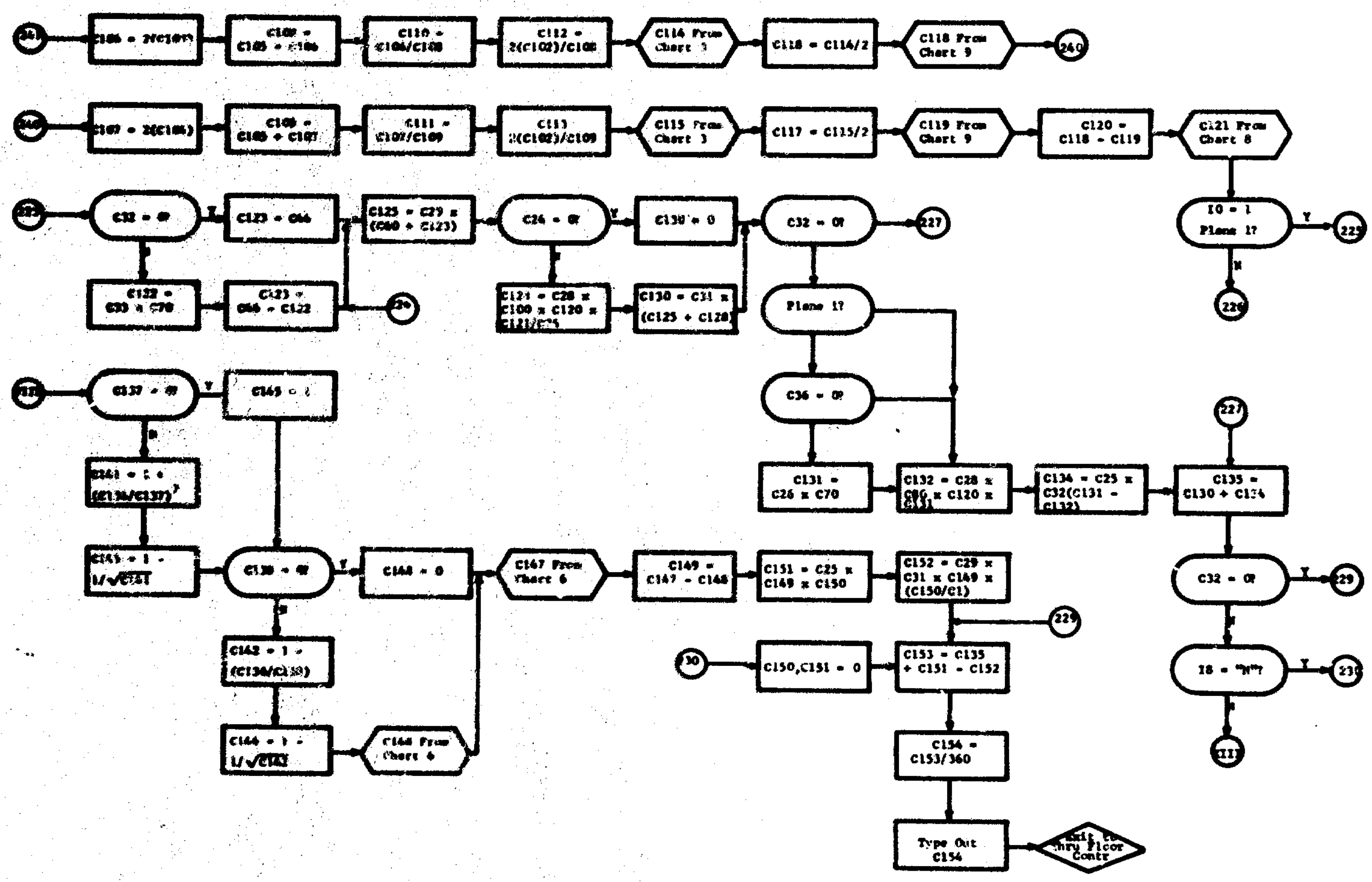
THROUGH CEILING COMPUTATION (CONT'D.)



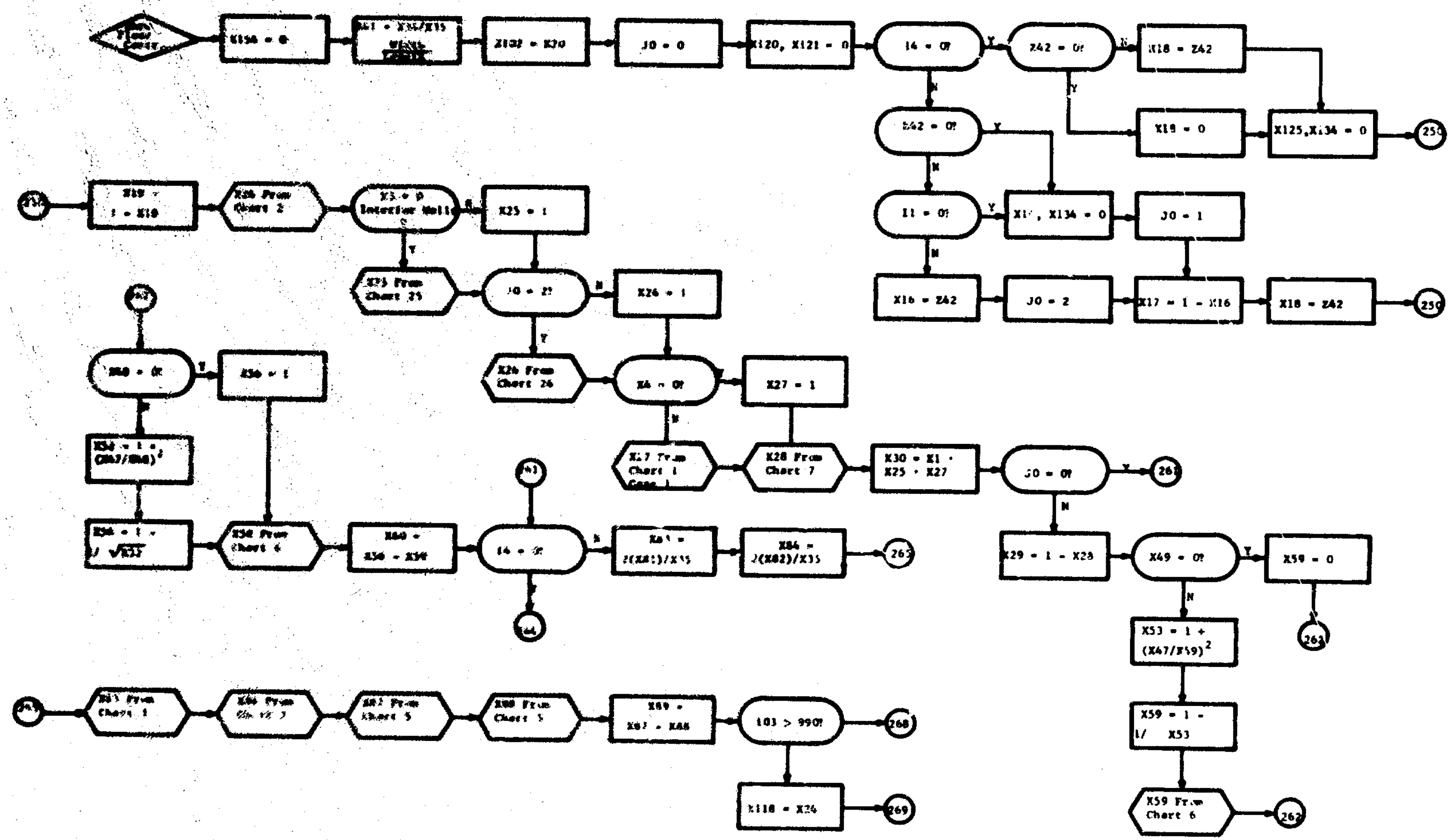
DETECTOR STORY CONTRIBUTION



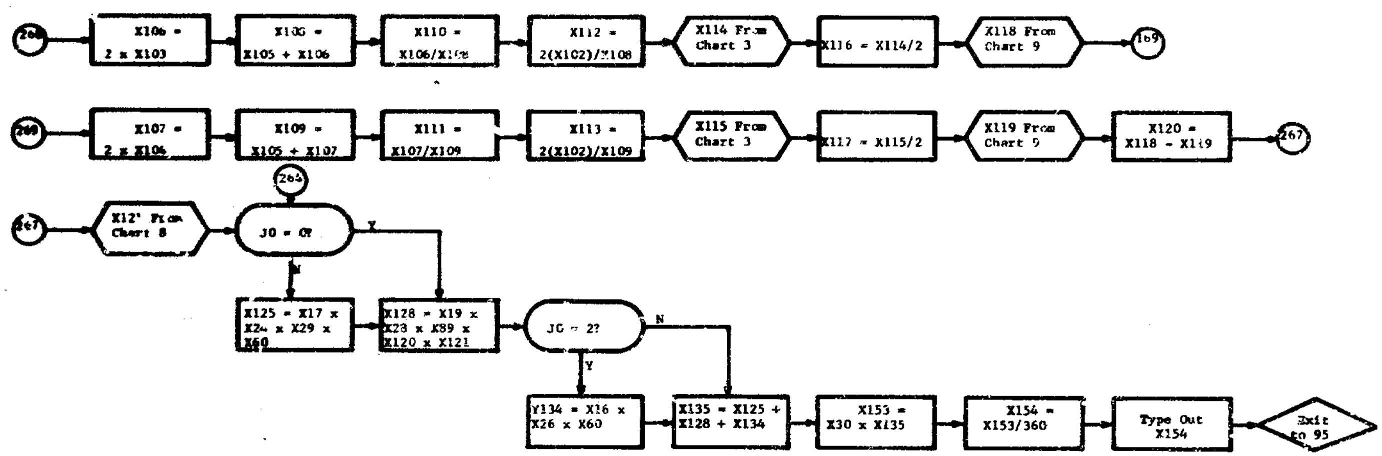
DETECTOR STORY CONTRIBUTION (CONT'D.)



DETECTOR STORY CONTRIBUTION (CONT'D.)



THRUUGH FLOOR CONTRIBUTION



THROUGH FLOOR CONTRIBUTION (CONT'D.)

TAB 5

Sample Printout

Z 0060	20000000 01	Z 0061	11200000 03										
K 0005	00000000010												
D 0154	00000000 00												
C 0154	13563617-02												
X 0154	37482404-02												
Z 0177	51046021-02	I 0009	00000000002	K 0005	00000000010	I 0000	00000000001						
D 0154	00000000 00												
C 0154	51172430-03												
X 0154	00000000 00												
Z 0177	51172430-03	I 0009	00000000002	K 0005	00000000010	I 0000	00000000002						
D 0154	00000000 00												
C 0154	00000000 00												
X 0154	00000000 00												
Z 0177	00000000 00	I 0009	00000000002	K 0005	00000000010	I 0000	00000000003						
Z 0174	18680860-02	Z 0175	00000000 00	Z 0176	37482404-02	Z 0178	56163264-02	I 0009	2				
K 0005	00000000010												
Z 0180	16529889-01	Z 0181	13492588-05	Z 0182	00000000 00	Z 0183	16531238-01	Z 0184	0				
Z 0185	94448511-02	Z 0186	38464510-02	Z 0187	31805183-04	Z 0188	13323107-01	Z 0189	1				
Z 0190	56427786-02	Z 0191	00000000 00	Z 0192	81139844-02	Z 0193	13756763-01	Z 0194	2				

TAB 6

Definition of Output Variables

Z60 = Standard Location

Z61 = Facility No. of PART of PARTS

Y154 = Basement Overhead Contribution		for each plane of each sector of each story
C154 = Detector Story Contribution		
D154 = Contribution from Story Above Detector		
X154 = Contribution from Story Below Detector		

Z177 = Total Contribution from all Stories for this Plane. For Basement = C154 + Y154, for Other Stories = C154 + D154 + X154.

I9 = Story Number

K5 = Sector Number

ID = Plane Number

Z174 = Detector Story Contribution	sum of planes for each story and each sector
Z175 = Story Above Detector Contribution	
Z176 = Story Below Detector Contribution	

Z178 = Z174 + Z175 + Z176

Z180, Z185, Z190.....,Total Detector Story Contribution

Z181, Z186, Z191.....,Total Story Above Contribution

Z182, Z187, Z192.....,Total Story Below Contribution

Z183, Z188, Z193.....,Total Ground Contribution

Z184, Z189, Z194.....,Story Number

Key to Numbers

The numbers given in this printout are fractions (digits to the right of the decimal point) and its associated power of ten. Example:

33200 01 is $.332 \times 10^1 = 3.32$

Appendix E

NFSS Phase 2 Data Collection Form

Appendix E
NFSS Phase 2 Data Collection Form

NATIONAL FALLOUT SHELTER SURVEY
PHASE 2

OD FORM 1255-1 / 1 FEB. 65

1. PAGE

SECTION A

2. NAME AND ADDRESS OF BUILDING OR SPECIAL FACILITY (Abbreviate to fit in 50 spaces. Please print)

3. STANDARD LOCATION CODE

4. FIELD OFFICE | 5. CONT. NO. | 6. FACILITY NO. | 7. PART NO. | 8. REV. NO.

9. SPECIAL FACILITIES (Enter appropriate code numbers for one facility only)

(1) MINE | (2) CAVE | (3) TUNNEL | (4) SUBWAY | (5) UNDERPASS | (6) STORAGE | (7) BSMT. EXT. | (8) HWY. MIL. | (9) OTHER

CAT. | UNIT. | TONS | SQUL. | STAT. | CAT. | USE | CAT. | USE | STAT. | CAT. | PART | CAT. | USE | CAT. | TYPE | USE

TOT. POPULATION SERVED

CD AGENCY REG.: REGION | STATE | COUNTY | TWP. | MUN.

10. CROSS REFERENCE OTHER RELATED FORMS FOR THIS FACILITY: PART NO. | PAGE

11. IDENTIFY "OTHER" IF MARKED IN ITEM 9

(a) "OTHER" CATEGORY OF SPECIAL FACILITY

(b) "OTHER" TUNNEL USE

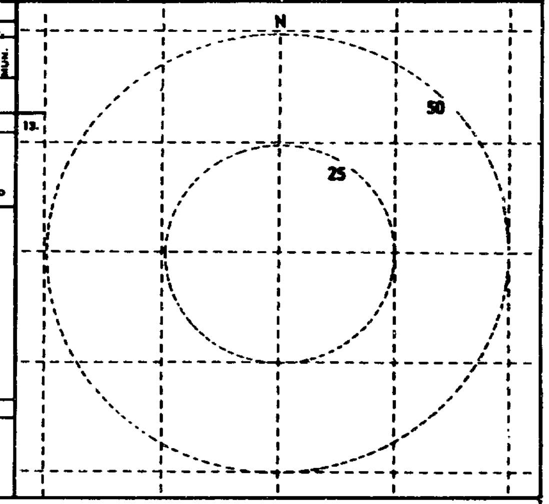
(c) "OTHER" STORAGE USE

12. RODENTS AND DESTRUCTIVE INSECTS

RODENTS:
- ☐ REPORTED PROBLEM
- ☐ OBSERVED EVIDENCE
- ☐ ACCESS OPENINGS

INSECTS:
- ☐ REPORTED PROBLEM
- ☐ TERMITE EVIDENCE OBSERVED
- ☐ OTHER INSECTS EVIDENCE OBSERVED

13.



14. REMARKS

SIGNATURE OF CERTIFIED A-E REPRESENTATIVE AND DATE

SIGNATURE | DATE | SIGNATURE | DATE

SECTION B - DATA SUMMARY (Use additional forms following consecutively in this book or in the next book, if necessary, and cross reference in Item 10.)

IDEN. DATA		EXISTING SHELTER OR SHIELDED AREA			SHIELDING IMPROVEMENT		VENTILATION IMPROVEMENT		AUXILIARY POWER		DISTANCE TO CENTER OF SHELTER AREA		SHELTER DIMENSIONS		SILL HEIGHT WINDOWS IN EXT. WALL (Ft. above floor)				INTERIOR PART. M=AVER. MASS (PSF) PARALLEL TO:								CROSS:			BASEMENT AREAWAYS							
STORY PHASE	PF CAT.	EXISTING SPACES	BLDG. FLOOR	DAMS	SHIELDED SPACES	COST PER SPACE	ADDED VENT. SPACES	COST PER SPACE	DEMAND LOAD (in KW)	COST PER SPACE	FROM SIDE A (Ft.)	FROM SIDE B (Ft.)	SIDE A (10 Ft.)	SIDE B (10 Ft.)	A	B	C	D	SIDE A NO	SIDE A M	SIDE B NO	SIDE B M	SIDE C NO	SIDE C M	SIDE D NO	SIDE D M	SPACE (Ft.)	M	TYPE	SIDE	L (10 S)	COR. DIST. (10 Ft.)	WIDTH (Ft.)	H HT (Ft.)	ROOKETS OR INSECTS	TYPE: N.E.B.	SPEC. FAC.

Appendix E (Continued)

Part 1 - SHIELDING

Sketch portions of facility and/or shelter area analyzed. Indicate part number, story number, or basement/subbasement. Show dimensions and identify features applicable to computation (use symbols, Table 5, EM). If multiple identical areas in a part, indicate number. Attach additional sketches, this size, if necessary.	Identify by number the chart(s) used in computation. List data, with values, required for chart solution (use symbols, Table 5, EM). State conclusions and key to sketch (psf to be added, type material, other necessary structural modifications). Estimate total cost for each shelter area. Also state basis for changes in PF or capacity recorded in Columns 15 through 20, Section B.

Part 2 - VENTILATION

Sketch facility and/or shelter area showing location of mechanical improvements required for habitability (use accepted industry symbols).	List data to support conclusions (existing CFM fresh air natural; mechanical). State conclusions (CFM fresh/recirculated air required). Estimate total cost (fan unit, dampers, filters, ductwork, louvers, grilles, registers, switches, wiring).

Part 3 - ELECTRICAL

Sketch facility and/or shelter area showing location of electrical requirements for power and lighting (use accepted industry symbols). If standby generator to serve community or complex of facilities, state location.	List data to support conclusions (demand load in kw for each electrical requirement). If standby generator required, describe characteristics (kw, dc/ac, phase, cycle, voltage, diesel/gasoline, fuel consumption at full load). Estimate total cost (generator cost prorated for each shelter area; distribution feeder with accessories, power and lighting circuits, circuit breakers, miscellaneous).

Appendix F

Shelter Area and Building Part Tabulations by Phase 2 Technical Shielding Characteristics

This appendix presents in tabular and graphical form the categorization of the Phase 2 structural data described in Chapter 4 for a statistical sample of 844 buildings. Shelter areas (stories containing shelter) and building parts (complex shaped buildings were divided into parts) are categorized by aperture sill height, interior partitions and areaways. Raw data used in this study are available for other analyses.

NFSS instructions for collecting data on sill heights, interior partitions, and areaways are paraphrased below:

1. Sill Heights: Enter the predominant sill height of the window openings (apertures) in exterior walls "A" through "D" above the appropriate floor level. Estimate to the nearest foot considered representative for the majority of the apertures in the wall. Enter X's if wall under consideration has no apertures.

2. Interior Partitions: The number and the average mass (estimated to the nearest 10 psf) of those partitions such as corridor walls extending parallel to Sides A, B, C and D (as used on the Phase 1 FOSDIC) will be recorded. Only those partitions which extend for a major portion of the evaluated shelter or shielded area and which lie between the exterior wall and the center of the shelter or shielded area will be recorded. Cross partitions, i.e. those separating adjacent rooms and not recorded elsewhere, will be recorded. The estimated average spacing in feet will be entered. The average mass is estimated to the nearest 10 psf. Enter 0's in appropriate columns if these are no significant partitions.

3. Basement Areaways: Data describing the location, length, distance from corner, width of basement areaways and the height of window openings in the basement walls exposed by the areaway are recorded as follows:

   a. Enter a letter A, B, C or D corresponding to the side of the building or building part in which the areaway is located.

   b. Enter the length of the areaway, expressed to the nearest (estimated) 10 percent of the length of the side in which it is located. If more than one areaway exists along the same wall, record the percent of their combined length.

   c. Enter the estimated distance, in tens of feet, from the corner of the building to the beginning of the areaway.

   d. Enter the width, to the nearest foot, of the areaway, e.g., the distance from the exterior face of the exposed basement wall to the inside (exposed) face of the areaway wall. If the areaway varies in width, record the estimated average effective width.

TABLE F-I

Building Parts with Areaways Reported

(1167 Building Parts)

PF Category	2	3	4	5	6	7	8	Total
Number	86	39	80	42	36	17	37	337
Fraction of Total Building Parts	.0737	.0334	.0686	.0360	.0308	.0146	.0317	.2888

TABLE F-II

Areaways - All PF Categories

Percent of Building Side Length	Areaway Width (in feet) 2	3	4	5	6	7	8	9	10	> 10	Total
	NUMBER										
0	1	2	2	1	1	0	0	0	0	0	7
10	18	64	38	9	8	1	2	1	2	2	145
20	13	45	27	13	5	4	3	2	3	5	120
30	7	23	9	8	2	1	0	0	0	4	54
40	2	5	10	3	0	0	0	1	2	1	24
50	1	9	10	5	0	0	0	1	1	2	29
60	0	5	4	8	3	0	1	0	1	3	25
70	0	4	3	2	1	0	1	0	0	0	11
80	0	2	6	4	1	0	0	0	0	0	13
90	2	11	14	22	4	2	1	1	2	6	65
											493
	FRACTION										
0	.0020	.0041	.0041	.0020	.0020	0	0	0	0	0	.0142
10	.0365	.1298	.0771	.0183	.0162	.0020	.0041	.0020	.0041	.0041	.2942
20	.0264	.0913	.0548	.0264	.0101	.0081	.0061	.0041	.0061	.0101	.2434
30	.0142	.0467	.0183	.0162	.0041	.0020	0	0	0	.0081	.1095
40	.0041	.0101	.0203	.0061	0	0	0	.0020	.0041	.0020	.0487
50	.0020	.0183	.0203	.0101	0	0	0	.0020	.0020	.0041	.0588
60	0	.0101	.0081	.0162	.0061	0	.0020	0	.0020	.0061	.0507
70	0	.0081	.0061	.0041	.0020	0	.0020	0	0	0	.0223
80	0	.0041	.0122	.0081	.0020	0	0	0	0	0	.0264
90	.0041	.0223	.0284	.0446	.0081	.0041	.0020	.0020	.0041	.0122	.1318
											1.0000

TABLE F-III

Areaways for PF Category 2 Shelter Areas

Percent of Building Side Length	Areaway Width (in feet) 2	3	4	5	6	7	8	9	10	> 10	Total
	NUMBER										
0	0	0	0	1	0	0	0	0	0	0	1
10	7	12	11	2	0	0	0	1	0	2	35
20	9	10	7	4	0	3	0	0	0	2	35
30	5	5	1	0	0	0	0	0	0	1	12
40	1	1	2	0	0	0	0	0	0	1	5
50	1	3	0	2	0	0	0	0	0	0	6
60	0	2	0	0	1	0	1	0	0	0	4
70	0	0	1	0	0	0	0	0	0	0	1
80	0	0	3	1	1	0	0	0	0	0	5
90	1	2	4	3	1	1	0	0	0	1	13
											117
	FRACTION										
0	0	0	0	.0085	0	0	0	0	0	0	.0085
10	.0600	.1026	.0940	.0171	0	0	0	.0085	0	.0171	.2992
20	.0770	.0855	.0600	.0342	0	.0256	0	0	0	.0171	.2992
30	.0427	.0427	.0085	0	0	0	0	0	0	.0085	.1026
40	.0085	.0085	.0171	0	0	0	0	0	0	.0085	.0427
50	.0085	.0256	0	.0171	0	0	0	0	0	0	.0513
60	0	.0171	0	0	.0085	0	.0085	0	0	0	.0342
70	0	0	.0085	0	0	0	0	0	0	0	.0085
80	0	0	.0256	.0085	.0085	0	0	0	0	0	.0427
90	.0085	.0171	.0342	.0256	.0085	.0085	0	0	0	.0085	.1111
											1.0000

TABLE F-IV

Areaways for PF Category 3 Shelter Areas

Percent of Building Side Length	Areaway Width (in feet) 2	3	4	5	6	7	8	9	10	>10	Total
	NUMBER										
0	0	0	0	0	0	0	0	0	0	0	0
10	0	5	1	1	2	0	0	0	0	0	9
20	0	6	2	2	0	0	0	0	0	1	11
30	0	2	1	1	0	0	0	0	0	0	4
40	0	1	2	3	0	0	0	1	0	0	7
50	0	0	3	1	0	0	0	1	0	1	6
60	0	2	0	0	0	0	0	0	0	1	3
70	0	1	0	0	0	0	0	0	0	0	1
80	0	1	1	0	0	0	0	0	0	0	2
90	0	3	1	1	1	1	0	0	0	2	9
											52
	FRACTION										
0	0	0	0	0	0	0	0	0	0	0	0
10	0	.0962	.0192	.0192	.0385	0	0	0	0	0	.1731
20	0	.1154	.0385	.0385	0	0	0	0	0	.0192	.2115
30	0	.0385	.0192	.0192	0	0	0	0	0	0	.0769
40	0	.0192	.0385	.0577	0	0	0	.0192	0	0	.1346
50	0	0	.0577	.0192	0	0	0	.0192	0	.0192	.1154
60	0	.0385	0	0	0	0	0	0	0	.0192	.0577
70	0	.0192	0	0	0	0	0	0	0	0	.0192
80	0	.0192	.0192	0	0	0	0	0	0	0	.0385
90	0	.0577	.0192	.0192	.0192	.0192	0	0	0	.0385	.1731
											1.0000

TABLE F-V

Areaways for PF Category 4 Shelter Areas

Percent of Building Side Length	2	3	4	5	6	7	8	9	10	>10	Total
	Areaway Width (in feet)										
	NUMBER										
0	1	0	1	0	1	0	0	0	0	0	3
10	6	12	13	2	2	0	0	0	0	0	35
20	1	9	6	4	2	1	0	1	0	1	25
30	0	6	3	3	0	0	0	0	0	0	12
40	0	0	2	0	0	0	0	0	0	0	2
50	0	0	2	1	0	0	0	0	1	0	4
60	0	0	2	6	2	0	0	0	1	1	12
70	0	1	1	0	1	0	1	0	0	0	4
80	0	0	1	2	0	0	0	0	0	0	3
90	1	4	7	8	1	0	1	1	1	0	24 / 124
	FRACTION										
0	.0081	0	.0081	0	.0081	0	0	0	0	0	.0242
10	.0484	.0968	.1048	.0161	.0161	0	0	0	0	0	.2822
20	.0081	.0726	.0484	.0323	.0161	.0081	0	.0081	0	.0081	.2016
30	0	.0484	.0242	.0242	0	0	0	0	0	0	.0968
40	0	0	.0161	0	0	0	0	0	0	0	.0161
50	0	0	.0161	.0081	0	0	0	0	.0081	0	.0323
60	0	0	.0161	.0484	.0161	0	0	0	.0081	.0081	.0968
70	0	.0081	.0081	0	.0081	0	.0081	0	0	0	.0323
80	0	0	.0081	.0161	0	0	0	0	0	0	.0242
90	.0081	.0323	.0565	.0645	.0081	0	.0081	.0081	.0081	0	.1935 / 1.0000

TABLE F-VI

Areaways for PF Category 5 Shelter Areas

Percent of Building Side Length	2	3	4	5	6	7	8	9	10	> 10	Total
	Areaway Width (in feet)										
	NUMBER										
0	0	1	0	0	0	0	0	0	0	0	1
10	1	9	1	0	1	0	0	0	1	0	13
20	2	5	4	2	0	0	1	0	1	0	15
30	1	7	2	2	0	0	0	0	0	0	12
40	1	2	1	0	0	0	0	0	0	0	4
50	0	0	2	1	0	0	0	0	0	0	3
60	0	1	0	2	0	0	0	0	0	0	3
70	0	0	0	1	0	0	0	0	0	0	1
80	0	0	1	0	0	0	0	0	0	0	1
90	0	0	1	7	1	0	0	0	0	2	11 / 64
	FRACTION										
0	0	.0156	0	0	0	0	0	0	0	0	.0156
10	[illegible]	.1406	.0156	0	.0156	0	0	0	.0156	0	.2031
20	.0313	.0781	.0625	.0313	0	0	.0156	0	.0156	0	.2344
30	.0156	.1094	.0313	.0313	0	0	0	0	0	0	.1875
40	.0156	.0313	.0156	0	0	0	0	0	0	0	.0625
50	0	0	.0313	.0156	0	0	0	0	0	0	.0469
60	0	.0156	0	.0313	0	0	0	0	0	0	.0469
70	0	0	0	.0156	0	0	0	0	0	0	.0156
80	0	0	.0156	0	0	0	0	0	0	0	.0156
90	0	0	.0156	.1094	.0156	0	0	0	0	.0313	.1719 / 1.0000

TABLE F-VII

Areaways for PF Category 6 Shelter Areas

Percent of Building Side Length	2	3	4	5	6	7	8	9	10	> 10	Total
	Areaway Width (in feet)										
	NUMBER										
0	0	0	0	0	0	0	0	0	0	0	0
10	1	14	8	1	3	0	0	0	0	0	27
20	1	7	1	1	0	0	0	0	1	0	11
30	1	2	2	0	1	0	0	0	0	2	8
40	0	0	1	0	0	0	0	0	1	0	2
50	0	2	2	0	0	0	0	0	0	0	4
60	0	0	1	0	0	0	0	0	0	0	1
70	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0
90	0	0	1	2	0	0	0	0	1	0	4 / 57
	FRACTION										
0	0	0	0	0	0	0	0	0	0	0	0
10	.0175	.2456	.1404	.0175	.0526	0	0	0	0	0	.4736
20	.0175	.1228	.0175	.0175	0	0	0	0	.0175	0	.1930
30	.0175	.0351	.0351	0	.0175	0	0	0	0	.0351	.1404
40	0	0	.0175	0	0	0	0	0	.0175	0	.0351
50	0	.0351	.0351	0	0	0	0	0	0	0	.0702
60	0	0	.0175	0	0	0	0	0	0	0	.0175
70	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0
90	0	0	.0175	.0351	0	0	0	0	.0175	0	.0702 / 1.0000

TABLE F-VIII

Areaways for PF Category 7 Shelter Areas

Percent of Building Side Length	2	3	4	5	6	7	8	9	10	>10	Total
	Areaway Width (in feet)										
	NUMBER										
0	0	0	0	0	0	0	0	0	0	0	0
10	0	3	1	0	0	0	0	0	0	0	4
20	0	3	2	0	1	0	0	0	1	0	7
30	0	0	0	1	0	0	0	0	0	1	2
40	0	0	1	0	0	0	0	0	1	0	2
50	0	1	1	0	0	0	0	0	0	0	2
60	0	0	1	0	0	0	0	0	0	1	2
70	0	1	0	1	0	0	0	0	0	0	2
80	0	1	0	0	0	0	0	0	0	0	1
90	0	0	0	0	0	0	0	0	0	0	0 / 22
	FRACTION										
0	0	0	0	0	0	0	0	0	0	0	0
10	0	.1364	.0455	0	0	0	0	0	0	0	.1818
20	0	.1364	.0909	0	.0455	0	0	0	.0455	0	.3182
30	0	0	0	.0455	0	0	0	0	0	.0455	.0909
40	0	0	.0455	0	0	0	0	0	.0455	0	.0909
50	0	.0455	.0455	0	0	0	0	0	0	0	.0909
60	0	0	.0455	0	0	0	0	0	0	.0455	.0909
70	0	.0455	0	.0455	0	0	0	0	0	0	.0909
80	0	.0455	0	0	0	0	0	0	0	0	.0455
90	0	0	0	0	0	0	0	0	0	0	0 / 1.0000

TABLE F-IX

Doorways for PF Category & Shelter Areas

Percent of Building Side Length	Doorway Width (in feet) 2	3	4	5	6	7	8	9	10	>10	Total
						NUMBER					
0	0	1	1	0	0	0	0	0	0	0	2
10	3	9	3	3	0	1	2	0	1	0	22
20	0	5	5	0	2	0	2	1	0	1	16
30	0	1	0	1	1	1	0	0	0	0	4
40	0	1	1	0	0	0	0	0	0	0	2
50	0	3	0	0	0	0	0	0	0	1	4
60	0	0	0	0	0	0	0	0	0	0	0
70	0	1	1	0	0	0	0	0	0	0	2
80	0	0	0	1	0	0	0	0	0	0	1
90	0	2	0	1	0	0	0	0	0	1	4
											57
						FRACTION					
0	0	.0175	.0175	0	0	0	0	0	0	0	.0351
10	.0526	.1579	.0526	.0526	0	.0175	.0351	0	.0175	0	.3859
20	0	.0877	.0877	0	.0351	0	.0351	.0175	0	.0175	.2807
30	0	.0175	0	.0175	.0175	.0175	0	0	0	0	.0702
40	0	.0175	.0175	0	0	0	0	0	0	0	.0351
50	0	.0526	0	0	0	0	0	0	0	.0175	.0702
60	0	0	0	0	0	0	0	0	0	0	0
70	0	.0175	.0175	0	0	0	0	0	0	0	.0351
80	0	0	0	.0175	0	0	0	0	0	0	.0175
90	0	.0351	0	.0175	0	0	0	0	0	.0175	.0702
											1.0000

TABLE F-X

Shelter Areas with Sill Heights Reported

PF Category	2	3	4	5	6	7	8	Total
			Basement Shelter Areas					
Number	161	77	143	91	69	32	52	625
Fraction of Total (1030) Basement Shelter Areas	.1563	.0748	.1388	.0883	.0670	.0311	.0505	.6068
			First Story Shelter Areas					
Number	84	23	53	24	11	5	6	206
Fraction of Total (262) First Story Shelter Areas	.3206	.0878	.2023	.0916	.0420	.0191	.0229	.7863
			Upper Story Shelter Areas					
Number	216	91	[illegible]	123	93	29	26	819
Fraction of Total (839) Upper Story Shelter Areas	.2556	.1085	[illegible]	.1466	.1110	.0346	.0310	.9762

TABLE F-XI

Sill Heights in Basement Shelter Areas

Sill Height	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
0	8	1	1	4	0	0	3	17
1	3	2	4	1	3	3	0	16
2	5	6	11	5	7	3	2	39
3	21	10	18	16	7	2	11	85
4	25	11	19	13	12	2	14	96
5	49	24	38	26	12	5	6	160
6	35	11	28	15	14	5	9	117
7	8	7	11	6	5	1	2	40
8	6	3	6	2	2	6	3	28
9	1	2	7	3	7	5	2	27
								625
				FRACTION				
0	.0128	.0016	.0016	.0064	0	0	.0048	.0272
1	.0048	.0032	.0064	.0016	.0048	.0048	0	.0256
2	.0080	.0096	.0176	.0080	.0112	.0048	.0032	.0624
3	.0336	.0160	.0288	.0256	.0112	.0032	.0176	.1360
4	.0400	.0176	.0304	.0208	.0192	.0032	.0224	.1536
5	.0784	.0384	.0608	.0416	.0192	.0080	.0096	.2560
6	.0560	.0176	.0448	.0240	.0224	.0080	.0144	.1872
7	.0126	.0112	.0176	.0096	.0080	.0016	.0032	.0640
8	.0096	.0048	.0096	.0032	.0032	.0096	.0048	.0448
9	.0016	.0032	.0112	.0048	.0112	.0080	.0032	.0432
								1.0000

TABLE F-XII

Sill Heights in First Story Shelter Areas

Sill Height	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
0	11	0	3	3	0	0	0	17
1	3	1	2	0	0	0	0	6
2	19	3	11	4	0	0	1	38
3	31	13	18	10	3	4	1	80
4	13	4	15	4	6	1	3	46
5	1	1	2	2	1	0	0	7
6	2	1	1	1	0	0	1	6
7	2	0	0	0	0	0	0	2
8	0	0	0	0	0	0	0	0
9	2	0	1	0	1	0	0	4
								206
				FRACTION				
0	.0534	0	.0146	.0146	0	0	0	.0825
1	.0146	.0049	.0097	0	0	0	0	.0291
2	.0922	.0146	.0534	.0194	0	0	.0049	.1845
3	.1505	.0631	.0874	.0485	.0146	.0194	.0049	.3884
4	.0631	.0194	.0728	.0194	.0291	.0049	.0146	.2233
5	.0049	.0049	.0097	.0097	.0049	0	0	.0340
6	.0097	.0049	.0049	.0049	0	0	.0049	.0291
7	.0097	0	0	0	0	0	0	.0097
8	0	0	0	0	0	0	0	0
9	.0097	0	.0049	0	.0049	0	0	.0194
								1.0000

TABLE F-XIII

Sill Heights in Upper Story Shelter Areas

Sill Height	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
0	2	0	1	0	0	0	0	3
1	5	4	1	2	5	3	0	20
2	95	40	110	60	60	17	22	404
3	99	36	107	51	37	9	2	339
4	12	4	16	8	11	0	1	52
5	1	1	2	0	0	0	0	4
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
								819
				FRACTION				
0	.0024	0	.0012	0	0	0	0	.0037
1	.0061	.0049	.0012	.0024	.0061	.0037	0	.0244
2	.1160	[illegible]	.1341	.0733	[illegible]	[illegible]	.0281	.4896
3	.1209	.0415	.1300	.0623	.0452	.0110	.0024	.4139
4	.0147	.0049	.0195	[illegible]	.0134	0	.0012	.0635
5	.0012	.0012	.0024	0	0	0	0	.0049
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
								1.0000

TABLE F-XIV

Shelter Areas with Parallel Partitions Reported

PF Category	2	3	4	5	6	7	8	Total
				Basement Shelter Areas				
Number	100	47	103	72	67	32	95	525
Fraction of Total (1030) Basement Shelter Areas	[illegible]	.0456	[illegible]	.0699	.0650	.0311	.0922	.5097
				First Story Shelter Areas				
Number	60	21	56	20	11	6	10	178
Fraction of Total (262) First Story Shelter Areas	.2290	[illegible]	.1908	.0763	.0420	.0229	.0382	.6794
				Upper Story Shelter Areas				
Number	146	40	200	105	72	26	27	656
Fraction of Total (830) Upper Story Shelter Areas	.1770	.0481	.2494	.1253	.0870	.0310	.0327	.7828

TABLE F-XV

Parallel Partitions in Basement Shelter Areas

Average psf per Shelter Area	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
5	13	7	6	2	6	1	6	41
10	13	5	9	7	10	3	7	54
15	12	4	10	14	5	3	10	58
20	25	10	13	11	11	5	20	95
25	4	2	3	4	1	0	6	20
30	4	2	10	5	7	3	9	40
35	6	1	3	1	2	0	3	16
40	2	3	11	2	3	4	6	31
45	8	4	12	8	5	8	6	51
50	4	1	3	3	1	0	6	18
60	5	3	5	5	7	2	4	31
70	4	1	1	1	1	2	2	12
80	1	2	4	1	0	0	2	10
90	2	1	4	1	6	0	3	17
100-195	5	1	8	6	1	0	5	26
200-300	0	0	0	1	1	1	0	3
>300	1	0	1	0	0	0	0	2
								525

TABLE F-XV (Continued)

Average psf per Shelter Area	PF Category 2	3	4	5	6	7	8	Total
				FRACTION				
5	.0248	.0133	.0114	.0038	.0114	.0019	.0114	.0781
10	.0248	.0095	.0171	.0133	.0190	.0057	.0133	.1029
15	.0229	.0076	.0190	.0267	.0095	.0057	.0190	.1105
20	.0476	.0190	.0248	.0210	.0210	.0095	.0381	.1810
25	.0076	.0038	.0057	.0076	.0019	0	.0114	.0381
30	.0076	.0038	.0190	.0095	.0133	.0057	.0171	.0762
35	.0114	.0019	.0057	.0019	.0038	0	.0057	.0305
40	.0038	.0057	.0210	.0038	.0057	.0076	.0114	.0590
45	.0152	.0076	.0229	.0152	.0095	.0152	.0114	.0971
50	.0076	.0019	.0057	.0057	.0019	0	.0114	.0343
60	.0095	.0057	.0095	.0095	.0133	.0038	.0076	.0590
70	.0076	.0019	.0019	.0019	.0019	.0038	.0038	.0229
80	.0019	.0038	.0076	.0019	0	0	.0038	.0190
90	.0038	.0019	.0076	.0019	.0114	0	.0057	.0324
100-195	.0095	.0019	.0152	.0114	.0019	0	.0095	.0495
200-300	0	0	0	.0019	.0019	.0019	0	.0057
>300	.0019	0	.0019	0	0	0	0	.0038
								1.0000

TABLE F-XVI

Parallel Partitions in First Story Shelter Areas

Average psf per Shelter Area	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
5	9	1	3	2	3	1	0	19
10	5	2	3	1	0	0	0	11
15	7	1	2	1	0	0	1	12
20	5	2	6	2	0	0	0	15
25	4	0	4	2	0	0	0	10
30	7	1	7	4	1	0	2	22
35	0	1	1	0	0	1	0	3
40	4	5	3	1	1	0	0	14
45	6	2	6	2	1	1	0	18
50	4	2	1	1	1	0	0	9
60	6	1	3	2	1	1	4	18
70	1	0	2	1	0	0	0	4
80	0	0	2	0	1	0	0	3
90	1	0	3	0	0	0	2	6
100-195	1	3	4	1	2	1	1	13
200-300	0	0	0	0	0	1	0	1
> 300	0	0	0	0	0	0	0	0
								178

TABLE F-XVII

Parallel Partitions in Upper Story Shelter Areas

Average psf per Shelter Area	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
5	15	11	7	2	4	2	0	41
10	19	7	8	1	4	1	4	44
15	10	17	45	20	5	2	0	99
20	34	8	26	16	11	5	14	114
25	6	5	28	10	5	5	1	60
30	11	7	39	17	7	1	0	82
35	8	1	1	0	0	0	0	10
40	16	3	21	10	2	0	2	54
45	5	1	8	0	1	0	1	16
50	12	5	2	3	2	0	0	24
60	6	1	3	5	8	1	0	24
70	1	0	0	0	1	0	0	2
80	1	0	4	1	2	0	0	8
90	1	0	2	7	2	0	2	14
100-195	4	2	8	8	9	5	2	38
200-300	0	0	7	4	9	4	0	24
> 300	0	0	0	1	0	0	1	2
								656

TABLE F-XVI (Continued)

Average psf per Shelter Area	PF Category 2	3	4	5	6	7	8	Total
				FRACTION				
5	.0506	.0056	.0169	.0112	.0169	.0056	0	.1067
10	.0281	.0112	.0169	.0056	0	0	0	.0618
15	.0393	.0056	.0112	.0056	0	0	.0056	.0674
20	.0281	.0112	.0337	.0112	0	0	0	.0843
25	.0225	0	.0225	.0112	0	0	0	.0562
30	.0393	.0056	.0393	.0225	.0056	0	.0112	.1235
35	0	.0056	.0056	0	0	.0056	0	.0169
40	.0225	.0281	.0169	.0056	.0056	0	0	.0787
45	.0337	.0112	.0337	.0112	.0056	.0056	0	.1011
50	.0225	.0112	.0056	.0056	.0056	0	0	.0506
60	.0337	.0056	.0169	.0112	.0056	.0056	.0225	.1011
70	.0056	0	.0112	.0056	0	0	0	.0225
80	0	0	.0112	0	.0056	0	0	.0169
90	.0056	0	.0169	0	0	0	.0112	.0337
100-195	.0056	.0169	.0225	.0056	.0112	.0056	.0056	.0730
200-300	0	0	0	0	0	.0056	0	.0056
> 300	0	0	0	0	0	0	0	0
								1.0000

TABLE F-XVII (Continued)

Average psf per Shelter Area	PF Category 2	3	4	5	6	7	8	Total
				FRACTION				
5	.0229	.0168	.0107	.0030	.0061	.0030	0	.0625
10	.0290	.0107	.0122	.0015	.0061	.0015	.0061	.0671
15	.0152	.0259	.0686	.0305	.0076	.0030	0	.1509
20	.0518	.0122	.0396	.0244	.0168	.0076	.0213	.1739
25	.0091	.0076	.0427	.0152	.0076	.0076	.0015	.0915
30	.0168	.0107	.0595	.0259	.0107	.0015	0	.1250
35	.0122	.0015	.0015	0	0	0	0	.0152
40	.0244	.0046	.0320	.0152	.0030	0	.0030	.0823
45	.0076	.0015	.0122	0	.0015	0	.0015	.0244
50	.0183	.0076	.0030	.0046	.0030	0	0	.0366
60	.0091	.0015	.0046	.0076	.0122	.0015	0	.0366
70	.0015	0	0	0	.0015	0	0	.0030
80	.0015	0	.0061	.0015	.0030	0	0	.0122
90	.0015	0	.0030	.0107	.0030	0	.0030	.0213
100-195	.0061	.0030	.0122	.0122	.0137	.0076	.0030	.0579
200-300	0	0	.0107	.0061	.0137	.0061	0	.0366
> 300	0	0	0	.0015	0	0	.0015	.0030
								1.0000

TABLE F-XVIII

Total Cross Partitions Reported by Type (All Shelter Areas)

Type	1	2	3	4	Total
Number	181	365	66	149	761
Fraction	.2379	.4796	.0867	.1958	1.0000

TABLE F-XIX

Shelter Areas with Types 1-4 Cross Partitions Reported

PF Category	2	3	4	5	6	7	8	Total
				Basement Shelter Areas				
Number	41	16	45	32	41	16	54	245
Fraction of Total (1030) Basement Shelter Areas	.0398	.0155	.0437	.0311	.0398	.0155	.0524	.2379
				First Story Shelter Areas				
Number	40	8	26	12	3	3	6	98
Fraction of Total (262) First Story Shelter Areas	.1527	.0305	.0992	.0458	.0115	.0115	.0229	.3740
				Upper Story Shelter Areas				
Number	108	45	119	60	51	16	19	418
Fraction of Total (838) Upper Story Shelter Areas	.1289	.0537	.1420	.0716	.0609	.0191	.0227	.4988

TABLE F-XX

Cross Partitions in Basement Shelter Areas

(Type 1)

Average psf	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	1	1	2	0	2	0	3	9
20	4	0	1	1	3	0	1	10
30	1	2	4	1	4	0	2	14
40	2	0	1	3	2	2	3	13
50	1	0	2	0	1	0	3	7
60	3	1	1	2	1	0	0	8
70	3	0	0	0	0	0	1	4
80	0	2	1	1	0	0	1	5
90	5	0	3	2	4	0	4	18
								88
				FRACTION				
10	.0114	.0114	.0227	0	.0227	0	.0341	.1023
20	.0455	0	.0114	.0114	.0341	0	.0114	.1136
30	.0114	.0227	.0455	.0114	.0455	0	.0227	.0591
40	.0227	0	.0114	.0341	.0227	.0227	.0341	1477
50	.0114	0	.0227	0	.0114	0	.0341	.0795
60	.0341	.0114	.0114	.0227	.0114	0	0	.0909
70	.0341	0	0	0	0	0	.0114	.0455
80	0	.0227	.0114	.0114	0	0	.0114	.0568
90	.0568	0	.0341	.0227	.0455	0	.0455	.2046
								1.0000

TABLE F-XX (Continued)

(Type 3)

Average psf	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	0	0	0	1	0	0	0	1
20	1	0	1	0	0	0	0	2
30	0	1	1	0	1	0	0	3
40	1	0	0	0	0	0	0	1
50	0	0	0	2	0	0	0	2
60	1	0	0	0	0	0	0	1
70	1	0	0	0	0	0	0	1
80	0	0	0	0	0	0	0	0
90	1	0	0	0	0	1	0	2
								13
				FRACTION				
10	0	0	0	.0769	0	0	0	.0769
20	.0769	0	.0769	0	0	0	0	.1539
30	0	.0769	.0769	0	.0769	0	0	.2309
40	.0769	0	0	0	0	0	0	.0769
50	0	0	0	.1538	0	0	0	.1538
60	.0769	0	0	0	0	0	0	.0769
70	.0769	0	0	0	0	0	0	.0769
80	0	0	0	0	0	0	0	0
90	.0769	0	0	0	0	.0769	0	.1538
								1.0000

TABLE F-XX (Continued)

(Type 2)

Average psf	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	0	1	0	2	3	0	0	6
20	5	1	2	2	5	2	5	22
30	2	2	4	1	1	2	3	15
40	4	2	9	5	4	2	5	29
50	3	1	3	1	0	0	5	13
60	1	0	2	2	6	0	3	14
70	0	0	0	0	0	0	1	1
80	0	1	0	1	2	0	2	6
90	1	1	6	3	1	7	5	24
								130
				FRACTION				
10	0	.0077	0	.0154	.0231	0	0	.0462
20	.0385	.0077	.0154	.0154	.0385	.0154	.0385	.0692
30	.0154	.0154	.0308	.0077	.0077	.0154	.0231	.1154
40	.0154	.0154	.0692	.0385	.0308	.0154	.0385	.2230
50	.0231	.0077	.0231	.0077	0	0	.0385	.1000
60	.0077	0	.0154	.0154	.0462	0	.0231	.1077
70	0	0	0	0	0	0	.0077	.0077
80	0	.0077	0	.0077	.0154	0	.0154	.0462
90	.0077	.0077	.0462	.0231	.0077	.0538	.0385	.1846
								1.0000

TABLE F-XX (Continued)

(Type 4)

Average psf	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	1	0	0	0	0	0	0	1
20	0	0	0	0	0	0	5	5
30	0	0	2	1	0	0	0	3
40	0	0	0	0	0	0	1	1
50	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
80	0	0	0	1	0	0	1	2
90	1	0	0	0	1	0	0	2
								14
				FRACTION				
10	.0714	0	0	0	0	0	0	.0714
20	0	0	0	0	0	0	.3571	.3571
30	0	0	.1429	.0714	0	0	0	.2143
40	0	0	0	0	0	0	.0714	.0714
50	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
80	0	0	0	.0714	0	0	.0714	.1429
90	.0714	0	0	0	.0714	0	0	.1429
								1.0000

TABLE F-XXI

Cross Partitions in First Story Shelter Areas

(Type 1)

Average psf	FF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	1	0	1	0	0	0	0	2
20	2	0	2	0	0	0	0	4
30	2	0	0	1	0	0	0	3
40	1	0	0	1	0	0	0	2
50	0	0	0	0	0	0	0	0
60	0	0	1	0	0	0	0	1
70	0	0	0	0	0	0	0	0
80	0	0	0	0	1	0	0	1
90	0	2	1	0	0	0	0	3
								16
				FRACTION				
10	.0625	0	.0625	0	0	0	0	.1250
20	.1250	0	.1250	0	0	0	0	.2500
30	.1250	0	0	.0625	0	0	0	.1875
40	.0625	0	0	.0625	0	0	0	.1250
50	0	0	0	0	0	0	0	0
60	0	0	.0625	0	0	0	0	.0625
70	0	0	0	0	0	0	0	0
80	0	0	0	0	.0625	0	0	.0625
90	0	.1250	.0625	0	0	0	0	.1875
								1.0000

TABLE F-XXI (Continued)

(Type 3)

Average psf	FF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	3	0	2	1	0	0	2	8
20	1	0	0	0	0	0	0	1
30	3	0	0	0	0	0	0	3
40	0	0	0	0	0	1	0	1
50	0	1	0	0	0	0	0	1
60	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	1	1
								15
				FRACTION				
10	.2000	0	.1333	.0667	0	0	.1333	.5332
20	.0667	0	0	0	0	0	0	.0667
30	.2000	0	0	0	0	0	0	.2000
40	0	0	0	0	0	.0667	0	.0667
50	0	.0667	0	0	0	0	0	.0667
60	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	.0667	.0667
								1.0000

TABLE F-XXI (Continued)

(Type 2)

Average psf	FF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	1	0	3	0	0	1	0	5
20	7	0	3	2	0	0	0	12
30	7	0	1	1	0	0	0	9
40	2	2	2	1	0	0	0	7
50	2	0	0	4	0	0	0	6
60	5	0	3	1	1	0	0	10
70	0	0	0	0	0	0	0	0
80	0	1	0	0	0	0	0	1
90	1	1	5	0	0	1	1	9
								59
				FRACTION				
10	.0169	0	.0508	0	0	.0169	0	.0847
20	.1186	0	.0508	.0339	0	0	0	.2035
30	.1186	0	.0169	.0169	0	0	0	.1525
40	.0339	.0339	.0339	.0169	0	0	0	.1186
50	.0339	0	0	.0678	0	0	0	.1017
60	.0847	0	.0508	.0169	.0169	0	0	.1696
70	0	0	0	0	0	0	0	0
80	0	.0169	0	0	0	0	0	.0169
90	.0169	.0169	.0847	0	0	.0169	.0169	.1525
								1.0000

TABLE F-XXI (Continued)

(Type 4)

Average psf	FF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	0	0	0	0	0	0	0	0
20	1	0	0	0	0	0	0	1
30	1	1	1	0	1	0	0	4
40	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
90	0	0	1	0	0	0	2	3
								8
				FRACTION				
10	0	0	0	0	0	0	0	0
20	.1250	0	0	0	0	0	0	.1250
30	.1250	.1250	.1250	0	.1250	0	0	.5000
40	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
90	0	0	.1250	0	0	0	.2500	.3750
								1.0000

TABLE F-XXII

Cr..se Partitions in Upper Story Shelter Areas

(Type 1)

Average psf	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	2	5	4	3	2	2	0	18
20	2	3	5	1	5	1	0	17
30	3	0	3	0	1	0	0	7
40	3	0	9	12	5	0	0	29
50	0	0	0	0	0	0	0	0
60	1	0	0	0	0	0	0	1
70	0	0	0	0	0	0	0	0
80	0	0	1	0	0	0	0	1
90	1	0	2	0	1	0	0	4
								77
				FRACTION				
10	.0260	.0649	.0519	.0390	.0260	.0260	0	.2338
20	.0260	.0390	.0649	.0130	.0649	.0130	0	.2208
30	.0390	0	.0390	0	.0130	0	0	.0909
40	.0390	0	.1169	.1558	.0649	0	0	.3766
50	0	0	0	0	0	0	0	0
60	.0130	0	0	0	0	0	0	.0130
70	0	0	0	0	0	0	0	0
80	0	0	.0130	0	0	0	0	.0130
90	.0130	0	.0260	0	.0130	0	0	.0519
								1.0000

TABLE F-XXII (Continued)

(Type 3)

Average psf	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	11	0	1	0	2	0	0	14
20	7	0	0	0	0	0	0	7
30	3	5	4	0	1	1	0	14
40	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
70	1	0	0	0	0	0	0	1
80	0	0	0	1	0	0	0	1
90	0	0	1	0	0	0	0	1
								38
				FRACTION				
10	.2895	0	.0263	0	.0526	0	0	.3685
20	.1842	0	0	0	0	0	0	.1842
30	.0789	.1316	.1053	0	.0263	.0263	0	.3684
40	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
70	.0263	0	0	0	0	0	0	.0263
80	0	0	0	.0263	0	0	0	.0263
90	0	0	.0263	0	0	0	0	.0263
								1.0000

TABLE F-XXII (Continued)

(Type 2)

Average psf	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	7	7	6	3	0	0	0	23
20	32	9	4	9	0	0	0	54
30	13	9	10	2	1	0	0	35
40	8	1	6	5	9	3	14	46
50	1	1	4	1	2	0	0	9
60	1	0	2	0	0	0	0	3
70	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
90	2	1	1	1	1	0	0	6
								176
				FRACTION				
10	.0398	.0398	.0341	.0170	0	0	0	.1307
20	.1818	.0511	.0227	.0511	0	0	0	.3068
30	.0739	.0511	.0568	.0114	.0057	0	0	.1989
40	.0455	.0057	.0341	.0284	.0511	.0170	.0795	.2614
50	.0057	.0057	.0227	.0057	.0114	0	0	.0511
60	.0057	0	.0114	0	0	0	0	.0170
70	0	[illegible]	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
90	.0114	.0057	.0057	.0057	.0057	0	0	.0341
								1.0000

TABLE F-XXII (Continued)

(Type 4)

Average psf	PF Category 2	3	4	5	6	7	8	Total
				NUMBER				
10	2	1	3	0	0	0	0	6
20	4	2	25	12	11	4	0	58
30	2	1	25	8	7	5	2	50
40	2	0	0	1	0	0	1	4
50	0	0	0	0	0	0	0	0
60	0	0	2	1	0	0	0	3
70	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
90	0	0	1	0	3	0	2	6
								127
				FRACTION				
10	.0157	.0079	.0236	0	0	0	0	.0472
20	.0315	.0157	.1969	.0945	.0866	.0315	0	.4568
30	.0157	.0079	.1969	.0630	.0551	.0394	.0157	.3937
40	.0157	0	0	.0079	0	0	.0079	.0315
50	0	0	0	0	0	0	0	0
60	0	0	.0157	.0079	0	0	0	.0236
70	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
90	0	0	.0079	0	.0236	0	.0157	.0472
								1.0000

FIGURE F-1

Estimated Distribution of All Areaways
According to Width and Length
(493 Areaways--Reported in 337 of 1167 Building Parts)

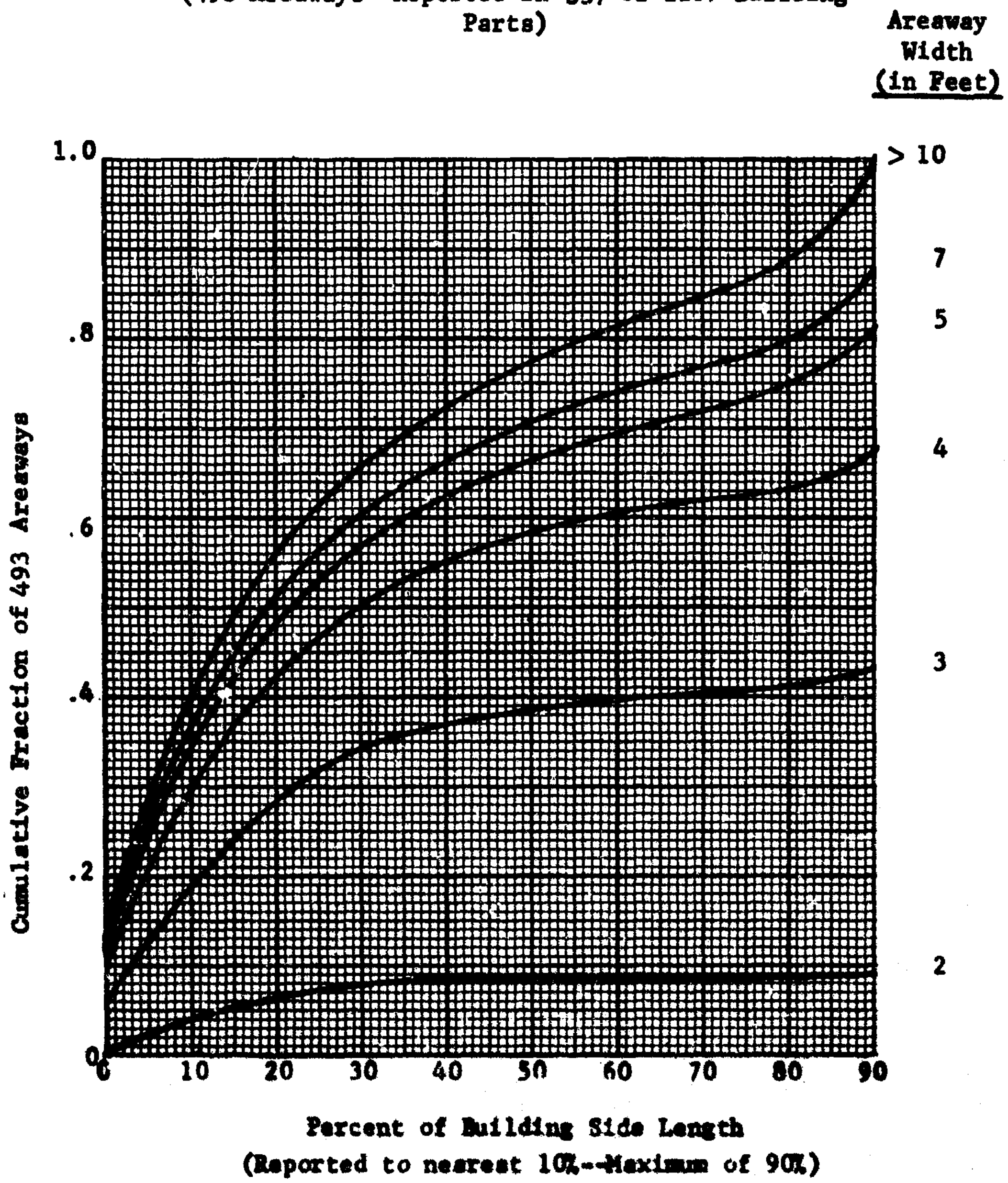
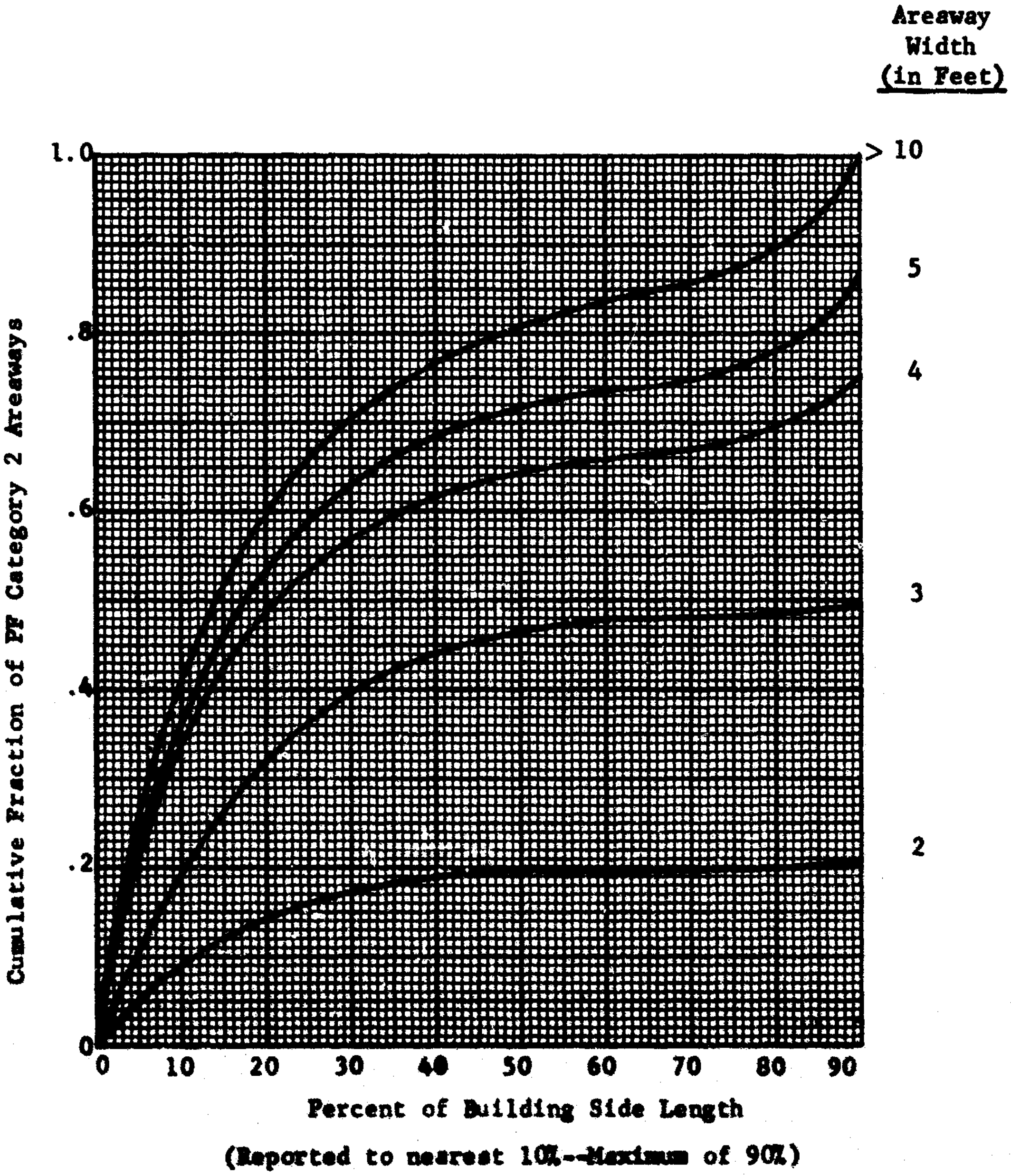


FIGURE F-2

Estimated Distribution of PF Category 2 Areaways*
According to Width and Length
(117 Areaways)



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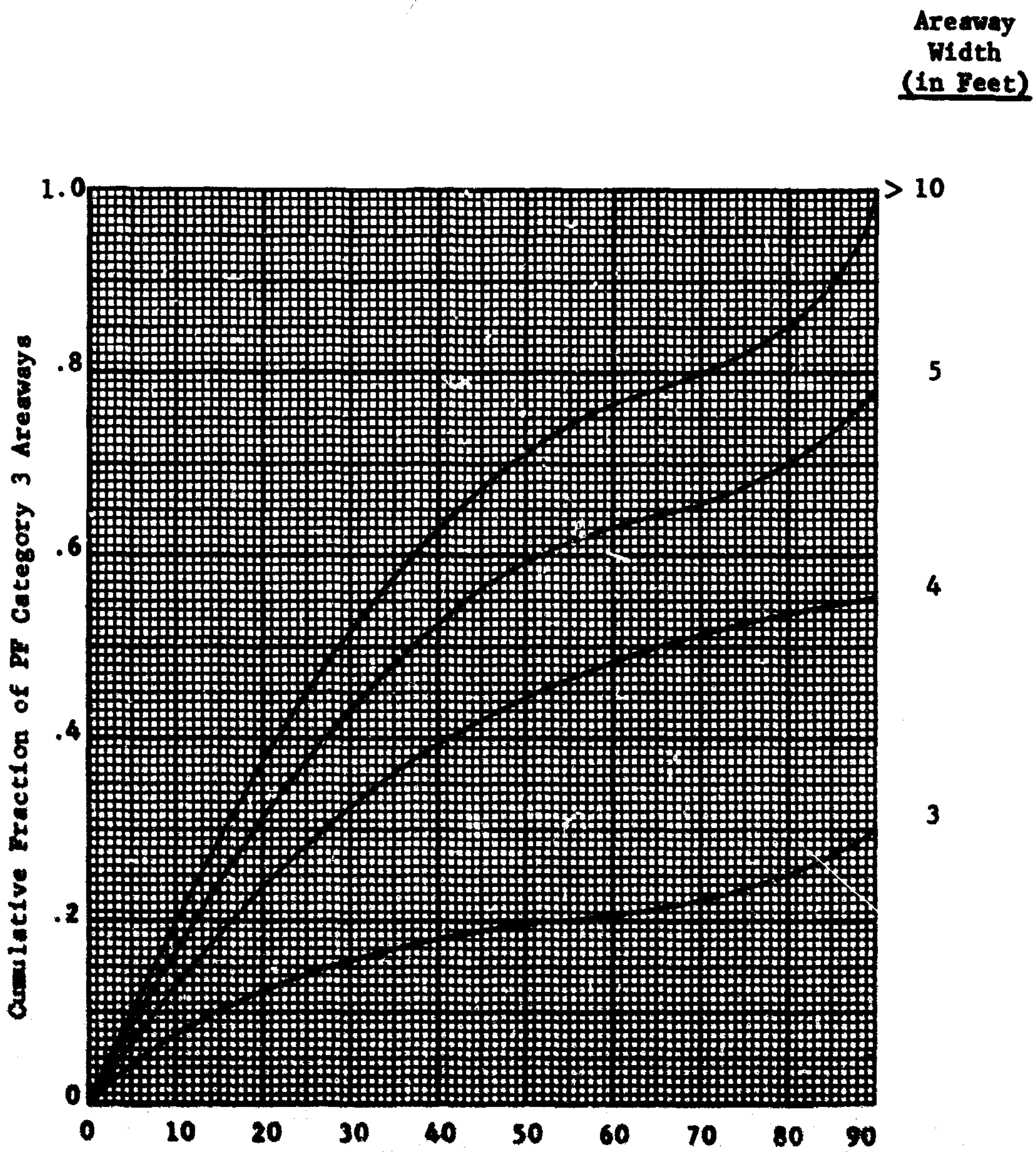
* Areaways reported adjacent to building parts with PF Category 2 shelter area.

FIGURE F-3

Estimated Distribution of PF Category 3 Areaways*
According to Width and Length
(52 Areaways)



Percent of Building Side Length
(Reported to nearest 10%--Maximum 90%)

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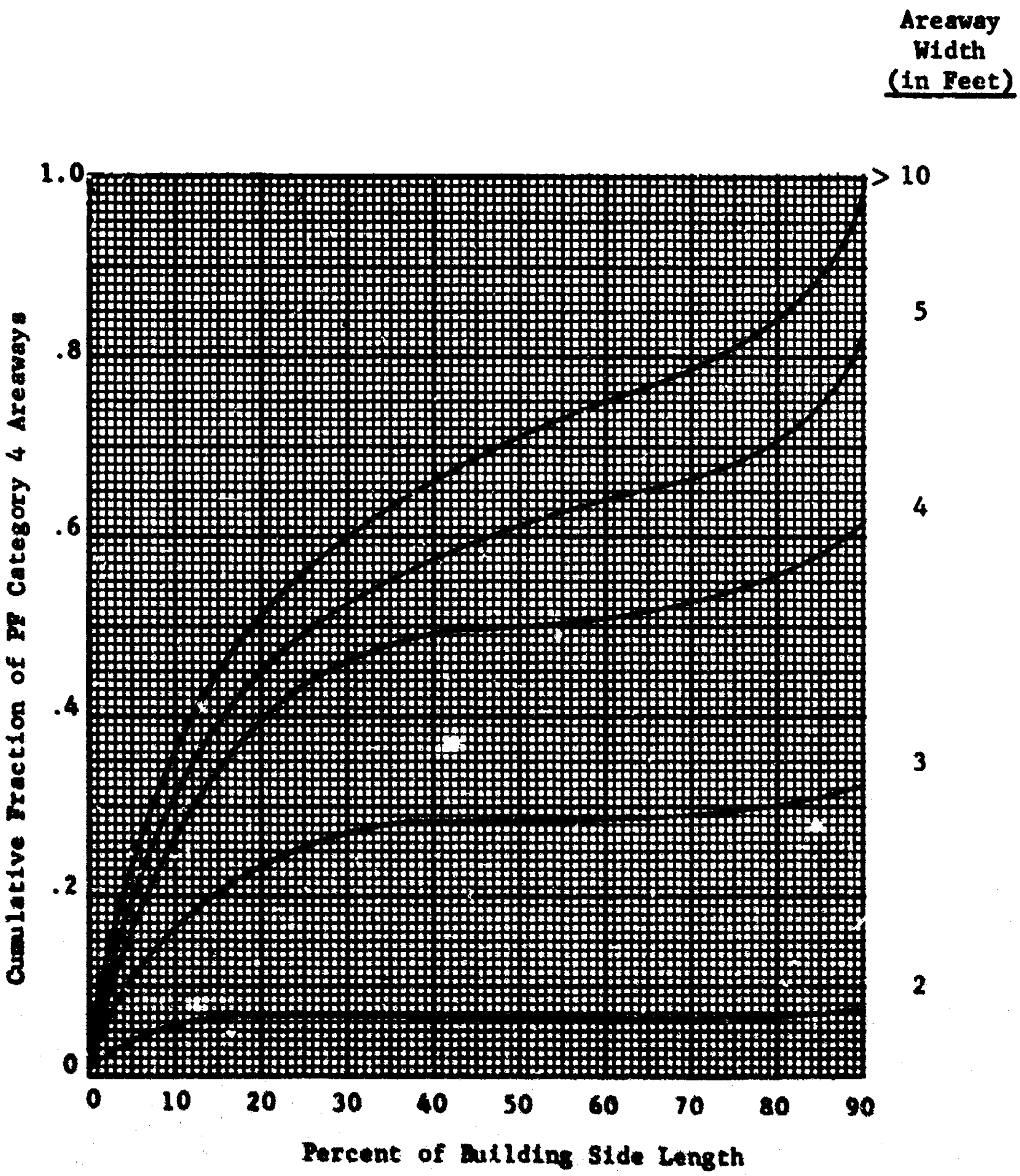
* Areaways reported adjacent to building parts with PF Category 3 shelter area.

FIGURE F-4

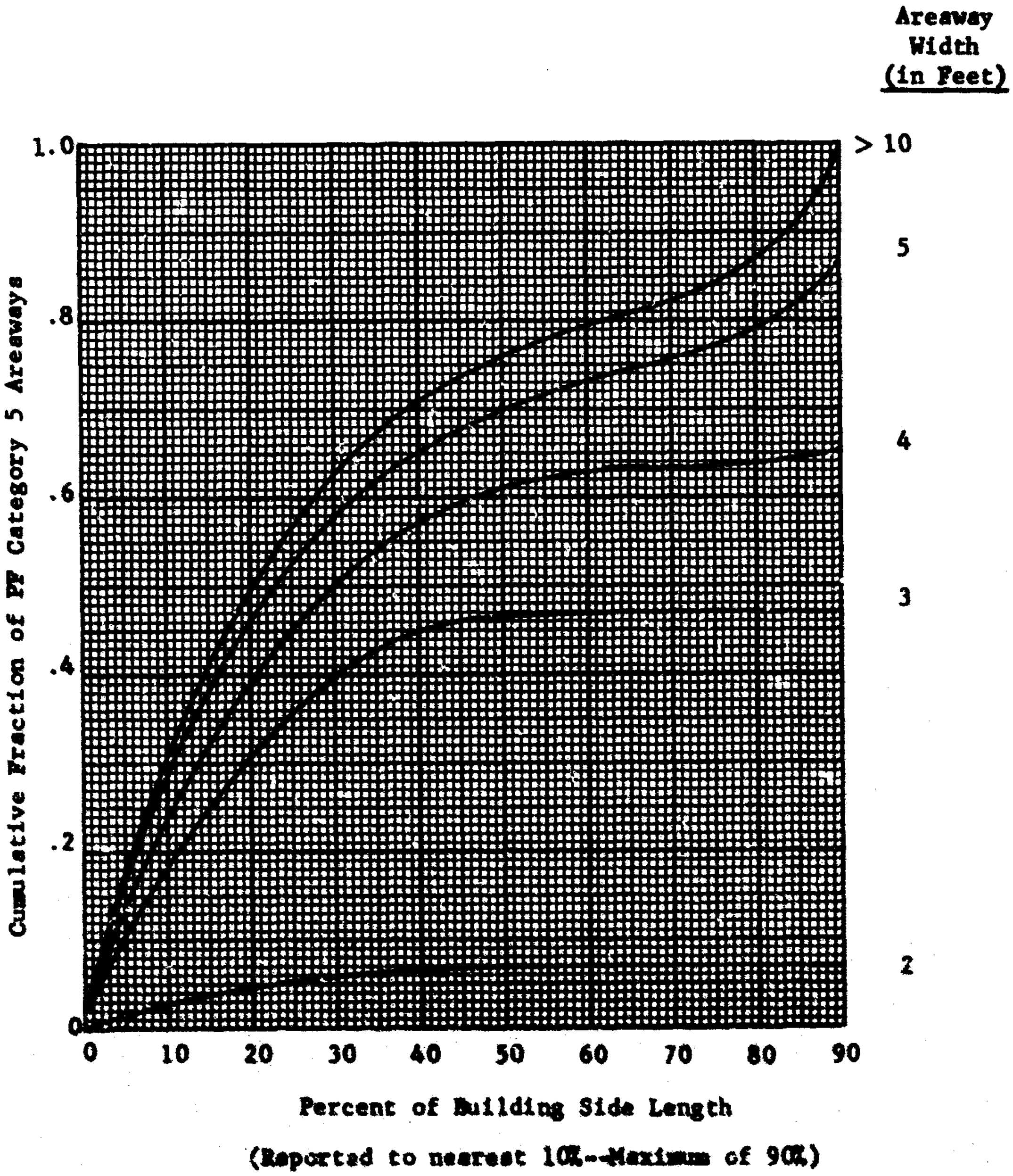
Estimated Distribution of FF Category 4 Areaways*
According to Width and Length
(124 Areaways)



* Areaways reported adjacent to building parts with FF Category 4 shelter area.

FIGURE F-5

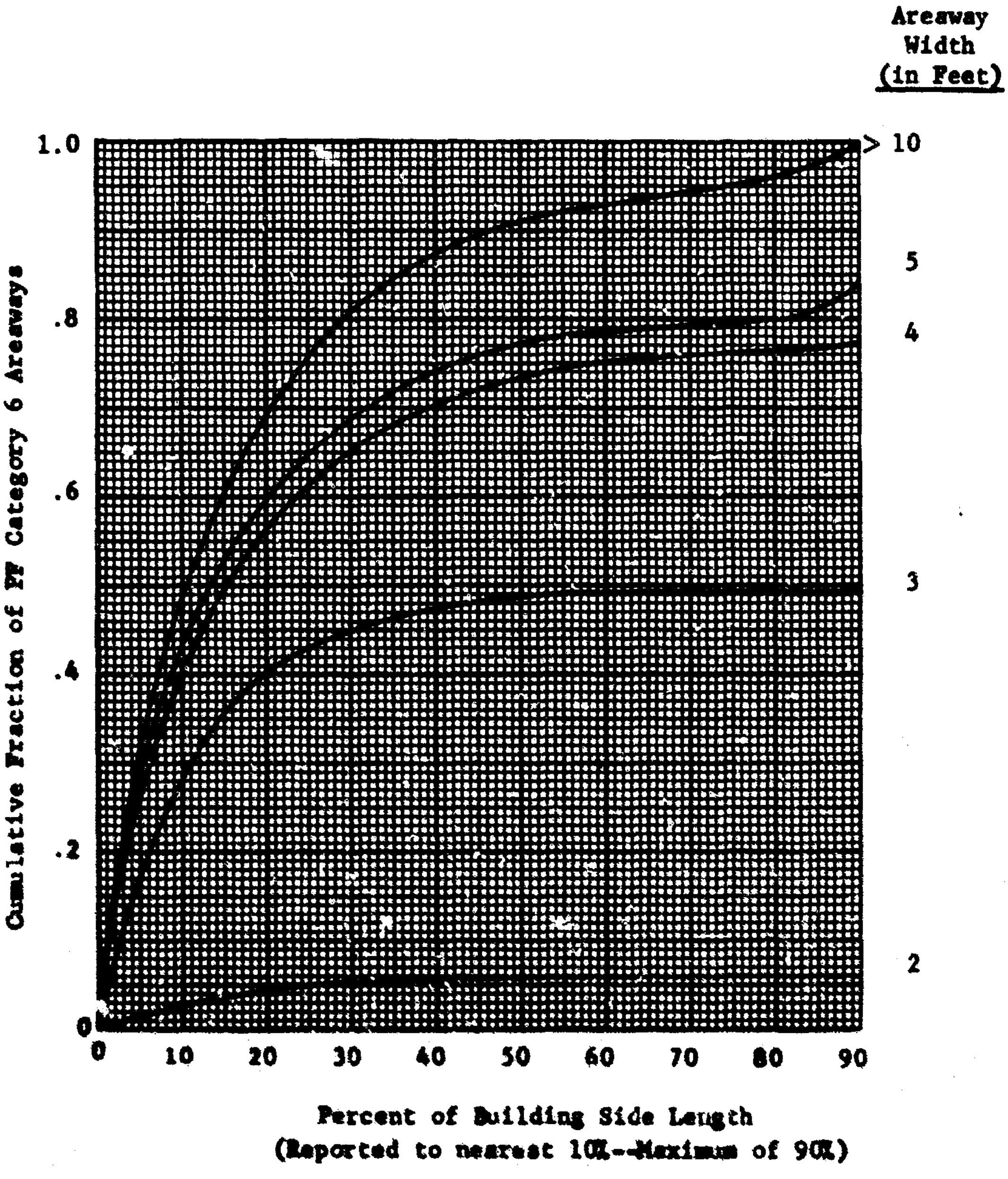
Estimated Distribution of PF Category 5 Areaways*
According to Width and Length
(64 Areaways)



* Areaways reported adjacent to building parts with PF Category 5 shelter area.

FIGURE F-6

Estimated Distribution of PF Category 6 Areaways*
According to Width and Length
(57 Areaways)



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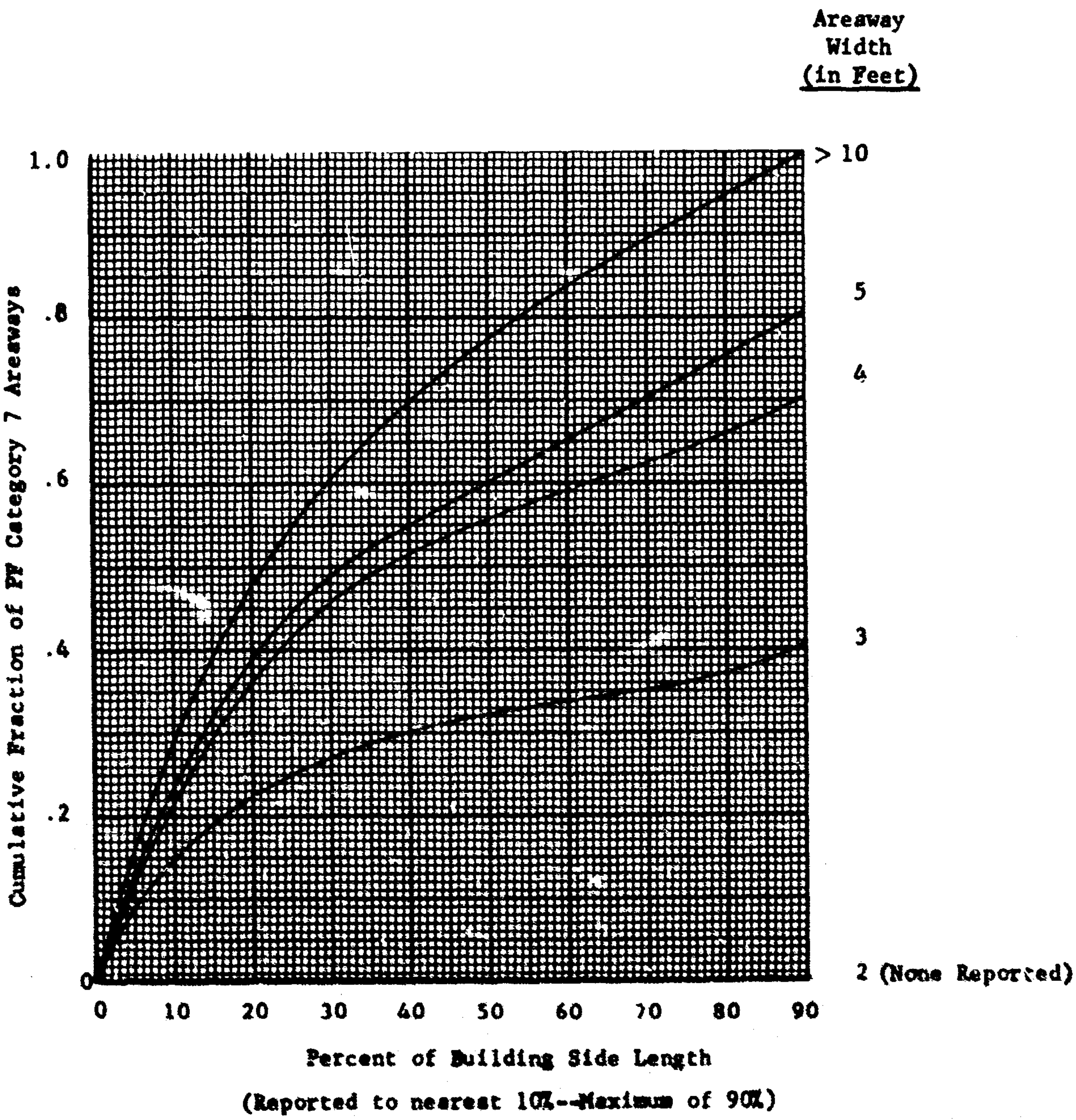
* Areaways reported adjacent to building parts with PF Category 6 shelter area.

FIGURE F-7

Estimated Distribution of PF Category 7 Areaways*
According to Width and Length
(22 Areaways)



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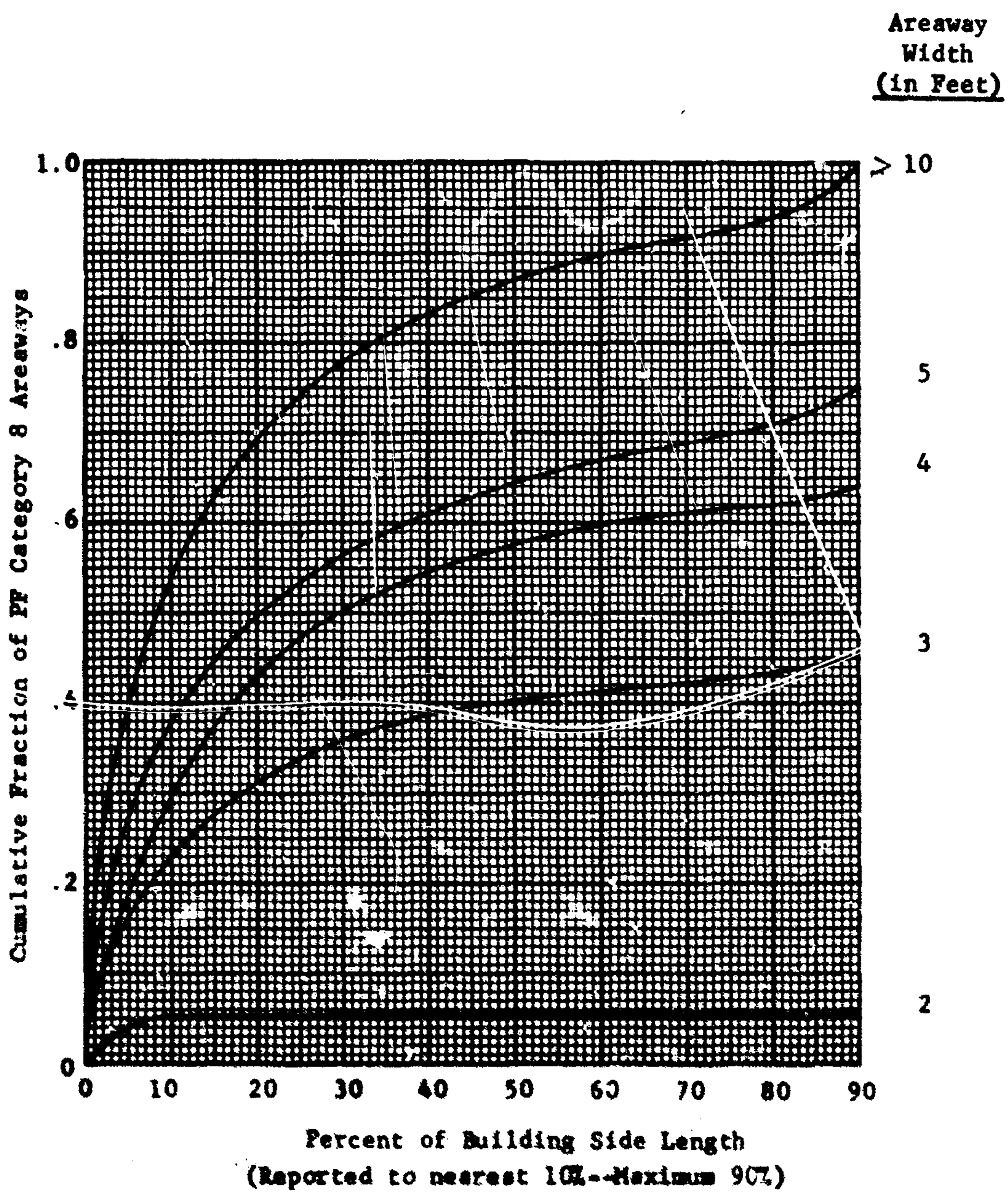
* Areaways reported adjacent to building parts with PF Category 7 shelter area.

FIGURE F-8

Estimated Distribution of PF Category 8 Areaways*
According to Width and Length
(57 Areaways)



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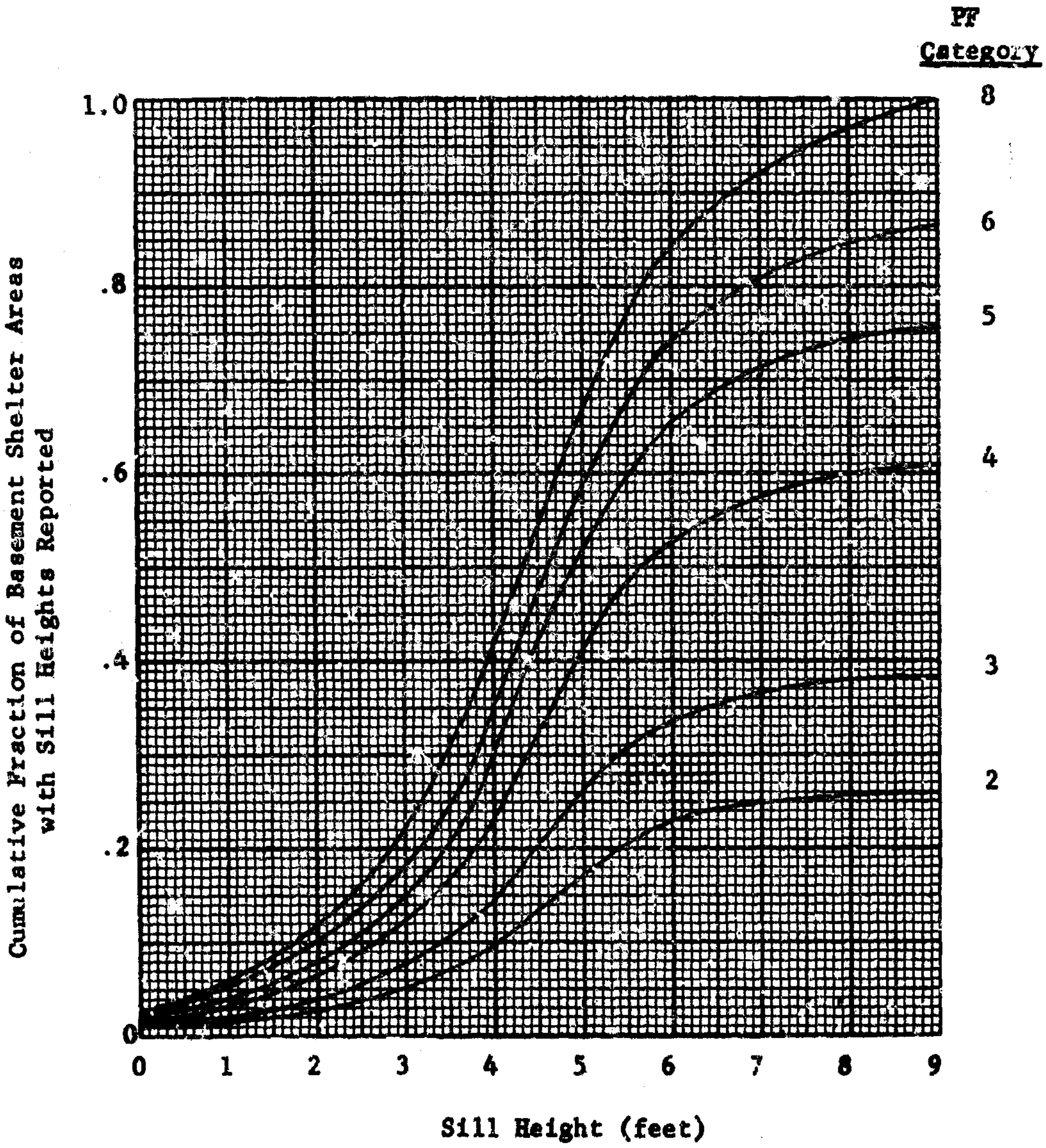
* Areaways reported adjacent to building parts with PF Category 8 shelter area.

FIGURE F-9

Estimated Distribution of Sill Heights in Basement Shelter Areas by PF Category
(625 Basement Shelter Areas with Sill Heights Reported)*

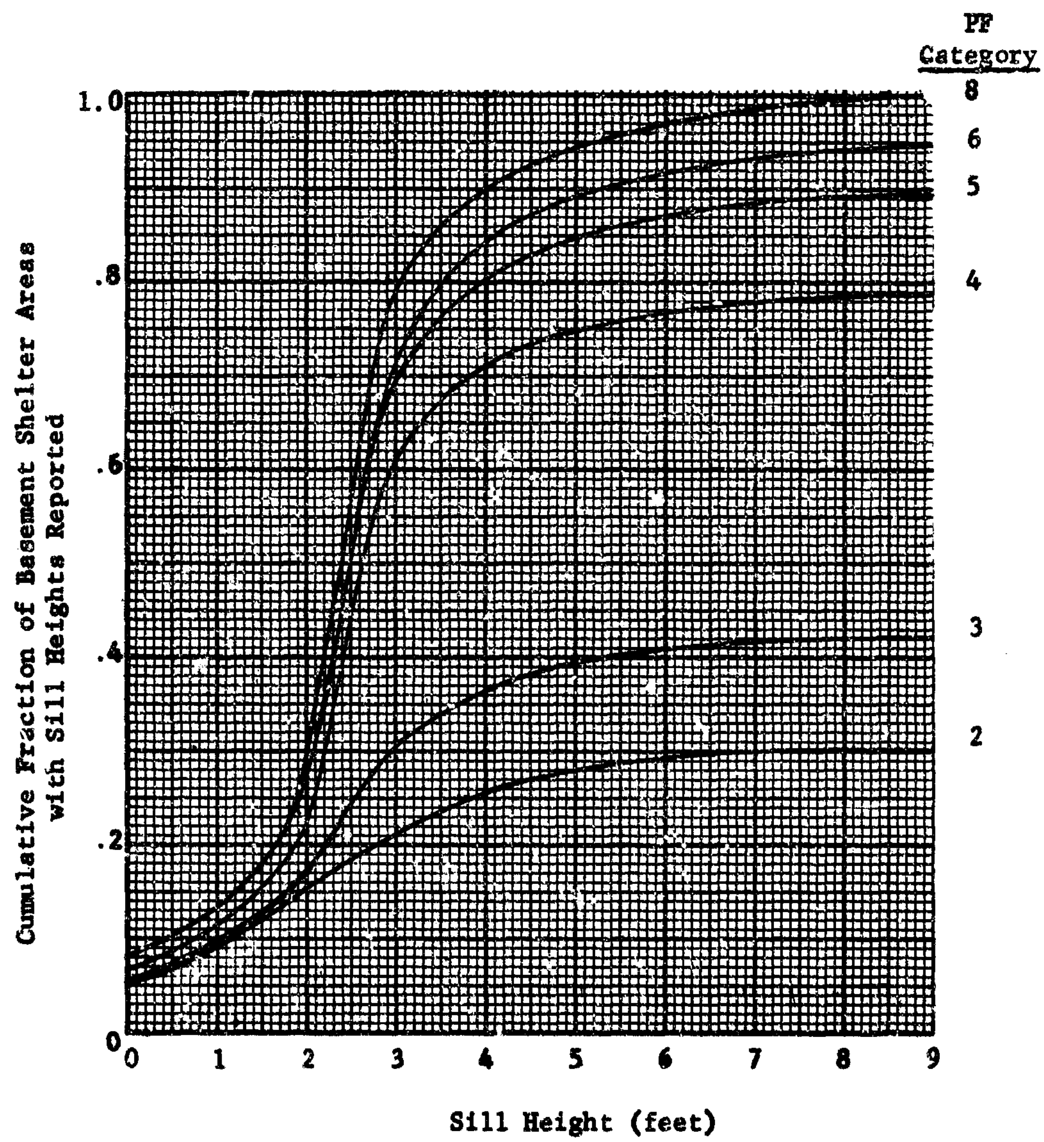


* Total of 1030 basement shelter areas in sample. Therefore, 405 shelter areas had no sill heights reported.

FIGURE F--10

Estimated Distribution of Sill Heights in First Story Shelter Areas by PF Category

(206 First Story Shelter Areas with Sill Heights Reported)*

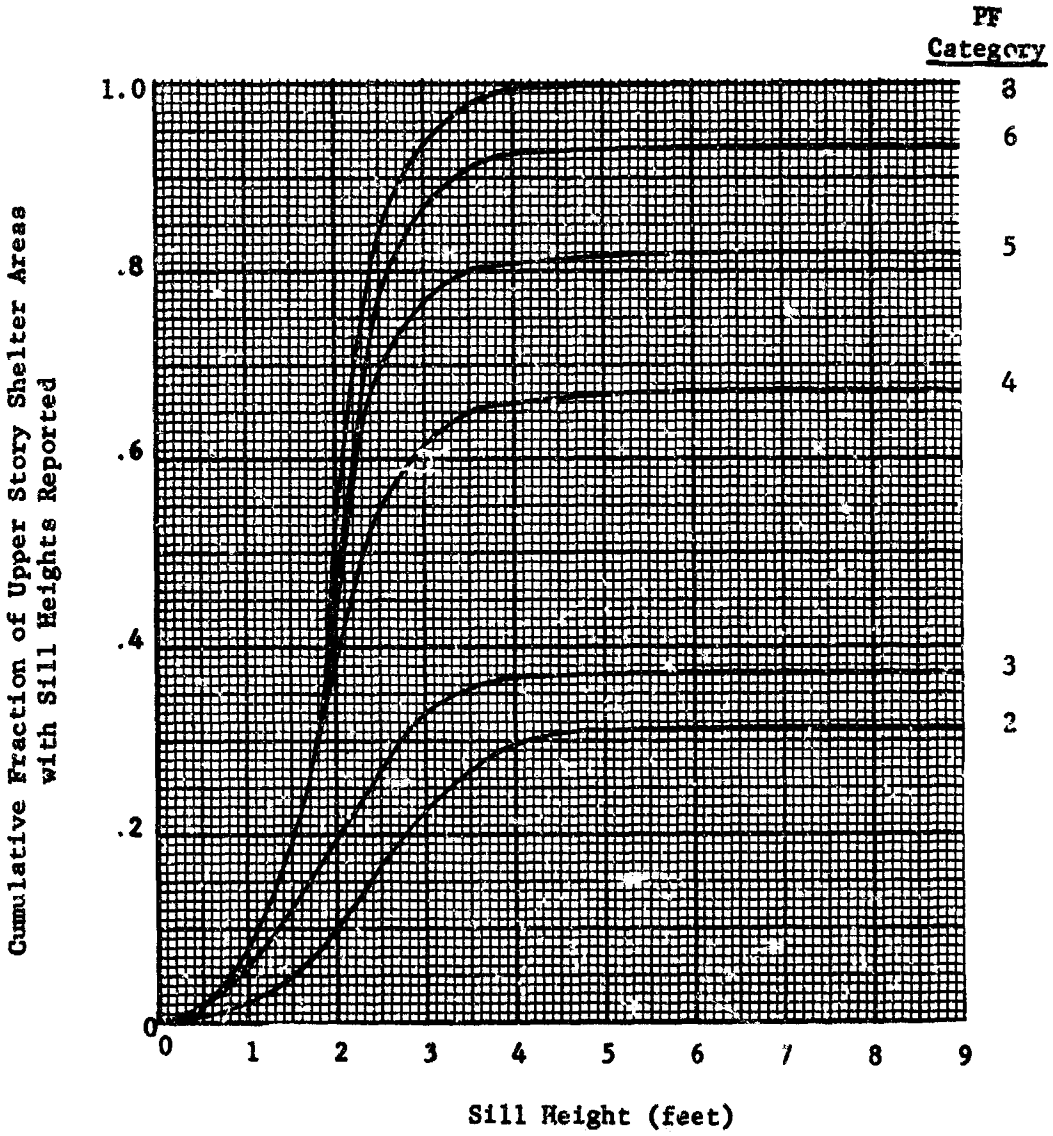


* Total of 262 first story shelter areas in sample. Therefore, 56 shelter areas had no sill heights reported.

FIGURE F-11

Estimated Distribution of Sill Heights in Upper Story Shelter Areas by PF Category

(819 Basement Shelter Areas with Sill Heights Reported)*



* Total of 838 upper story shelter areas in sample. Therefore, 19 shelter areas had no sill heights reported.

FIGURE F-12

Estimated Distribution of Parallel Partitions in Basement Shelter Areas by PF Category
(525 Basement Shelter Areas with Parallel Partitions Reported)

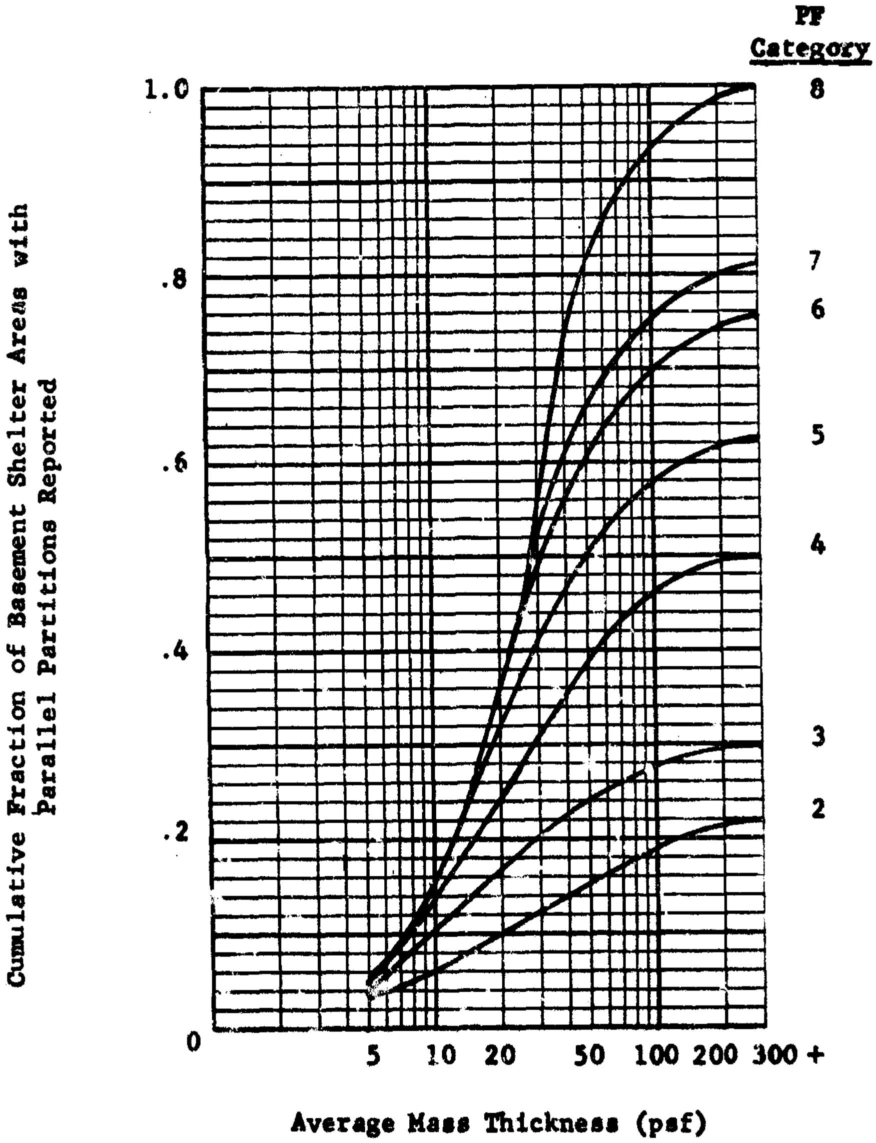


FIGURE F-13

Estimated Distribution of Parallel Partitions in First Story Shelter Areas by PF Category (178 First Story Shelter Areas with Parallel Partitions Reported)

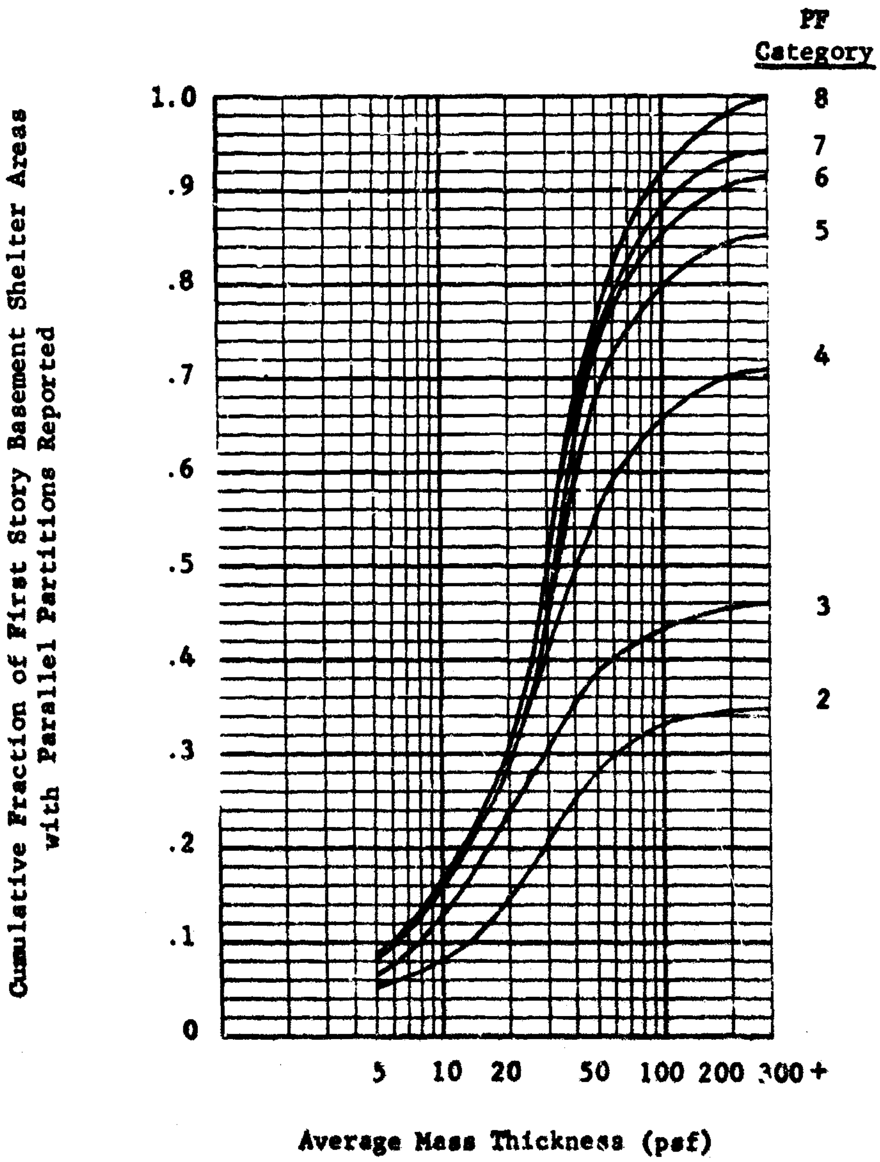


FIGURE F-14

Estimated Distribution of Parallel Partitions
in Upper Story Shelter Areas by PF Category
(656 Upper Story Shelter Areas with Parallel Partitions Reported)

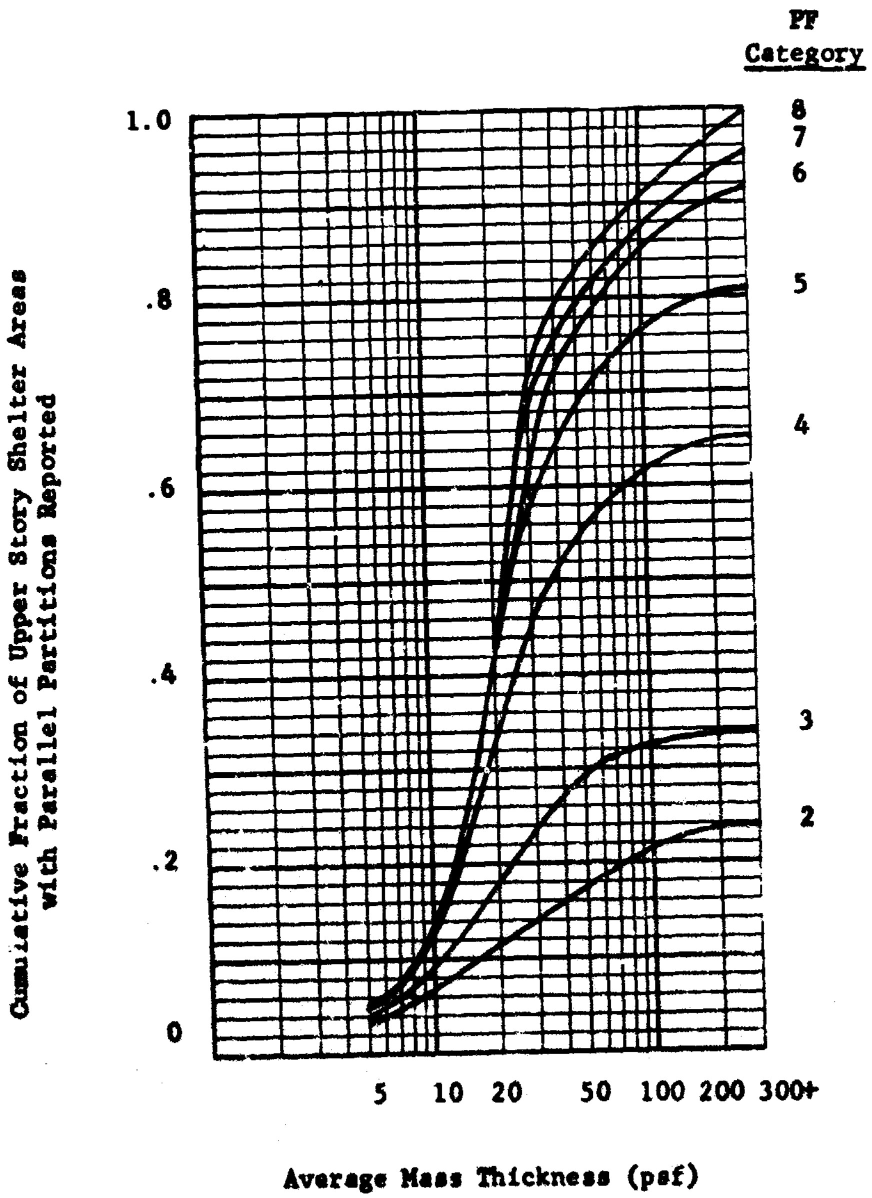


FIGURE F-15

<u>Estimated Distribution of Type 1 Cross Partitions in Basement Shelter Areas by PF Category</u>
(88 Basement Shelter Areas with Type 1 Cross Partitions Reported)

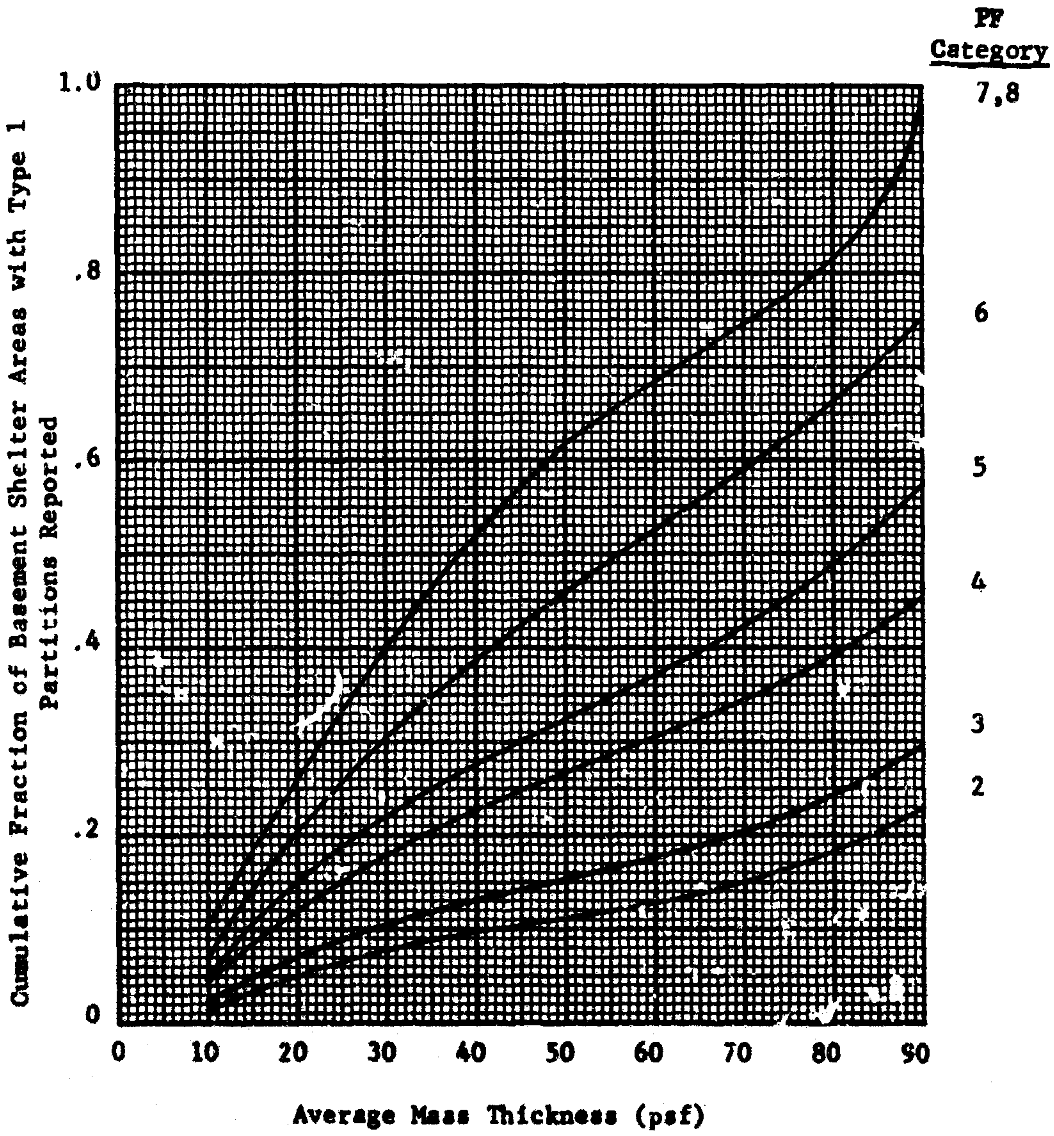


FIGURE F-16

Estimated Distribution of Type 2 Cross Partitions
in Basement Shelter Areas by PF Category
(130 Basement Shelter Areas with Type 2 Cross Partitions Reported)

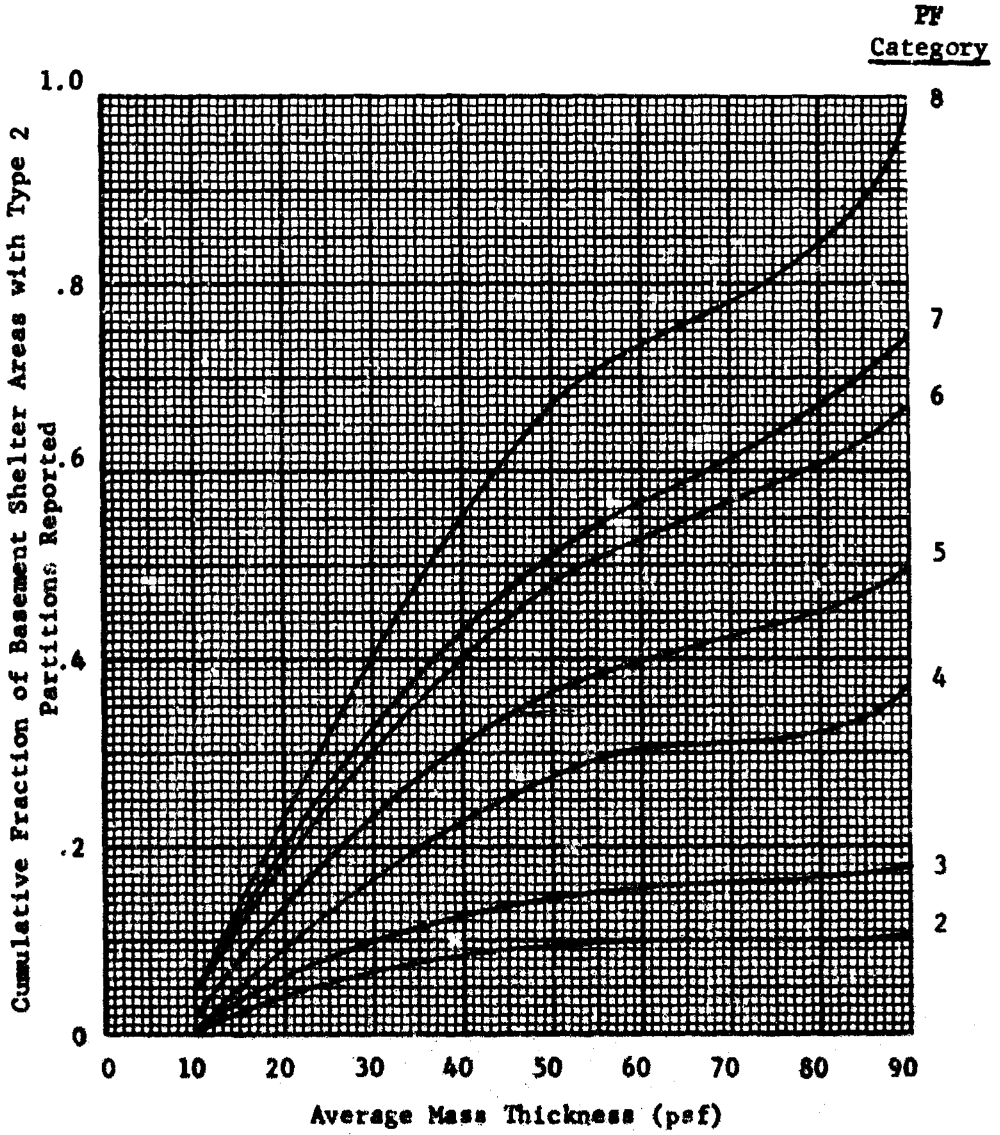


FIGURE F-17

Estimated Distribution of Type 3 Cross Partitions
in Basement Shelter Areas by PF Category
(13 Basement Shelter Areas with Type 3 Cross Partitions Reported)

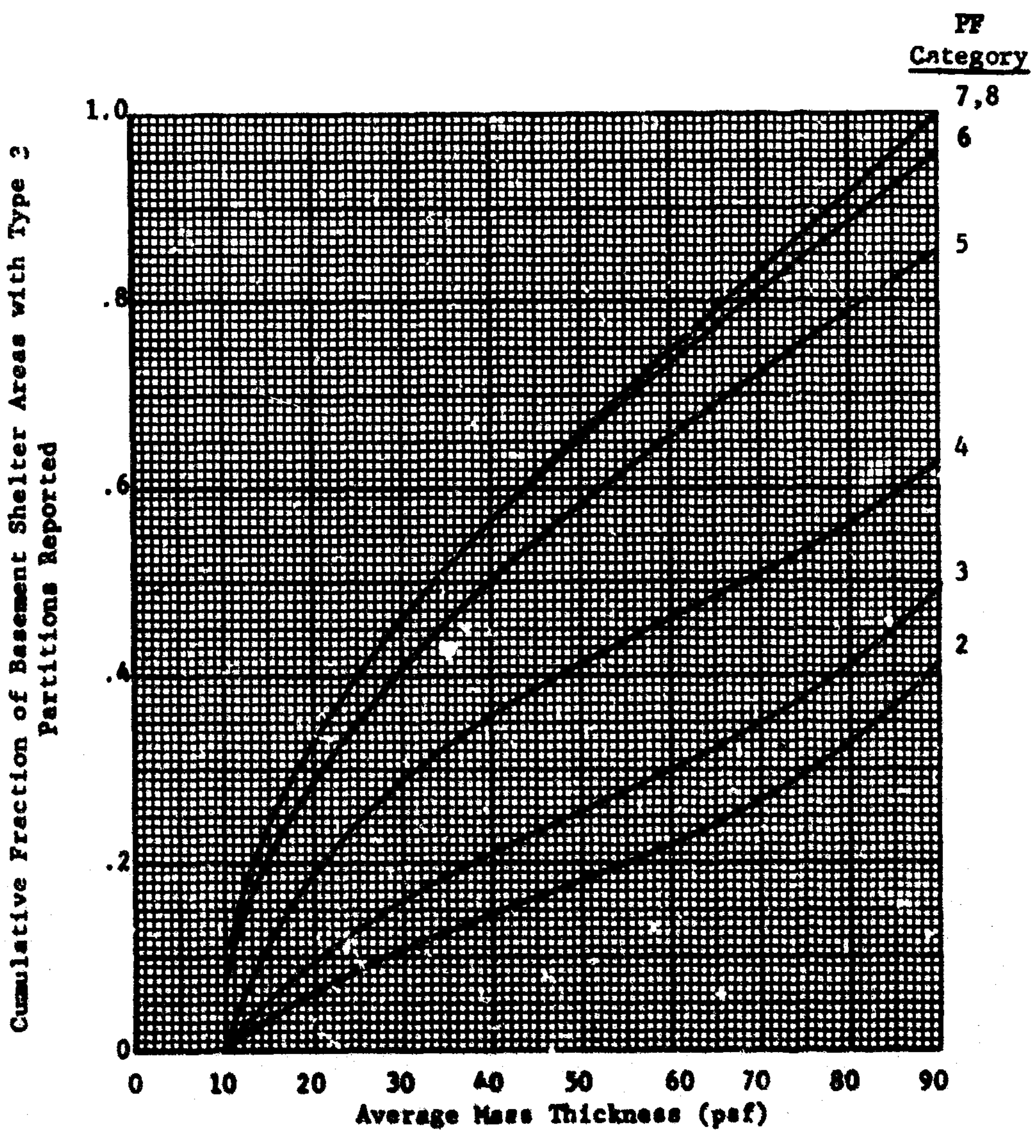


FIGURE F-18

Estimated Distribution of Type 4 Cross Partitions in Basement Shelter Areas by PF Category
(14 Basement Shelter Areas with Type 4 Cross Partitions Reported)

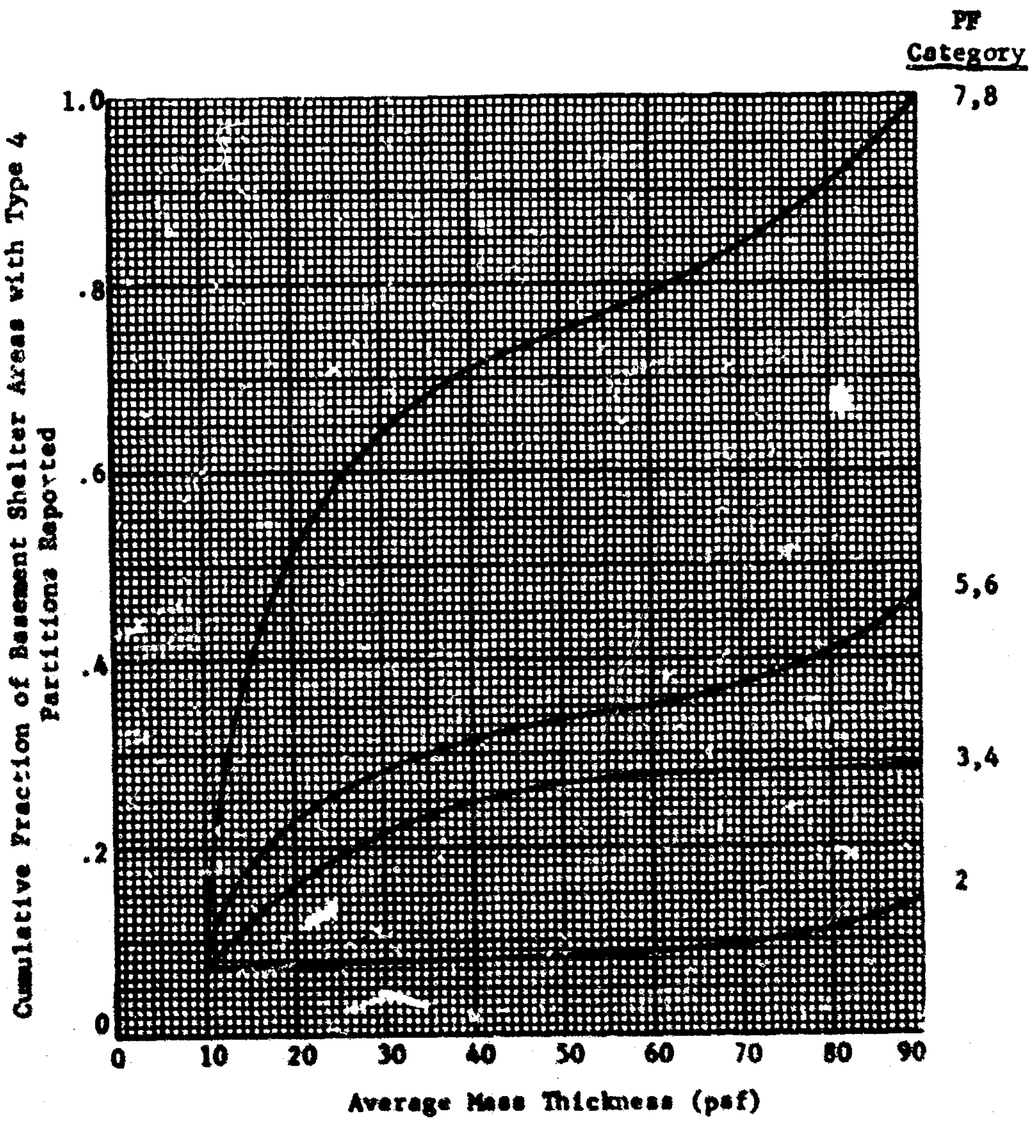
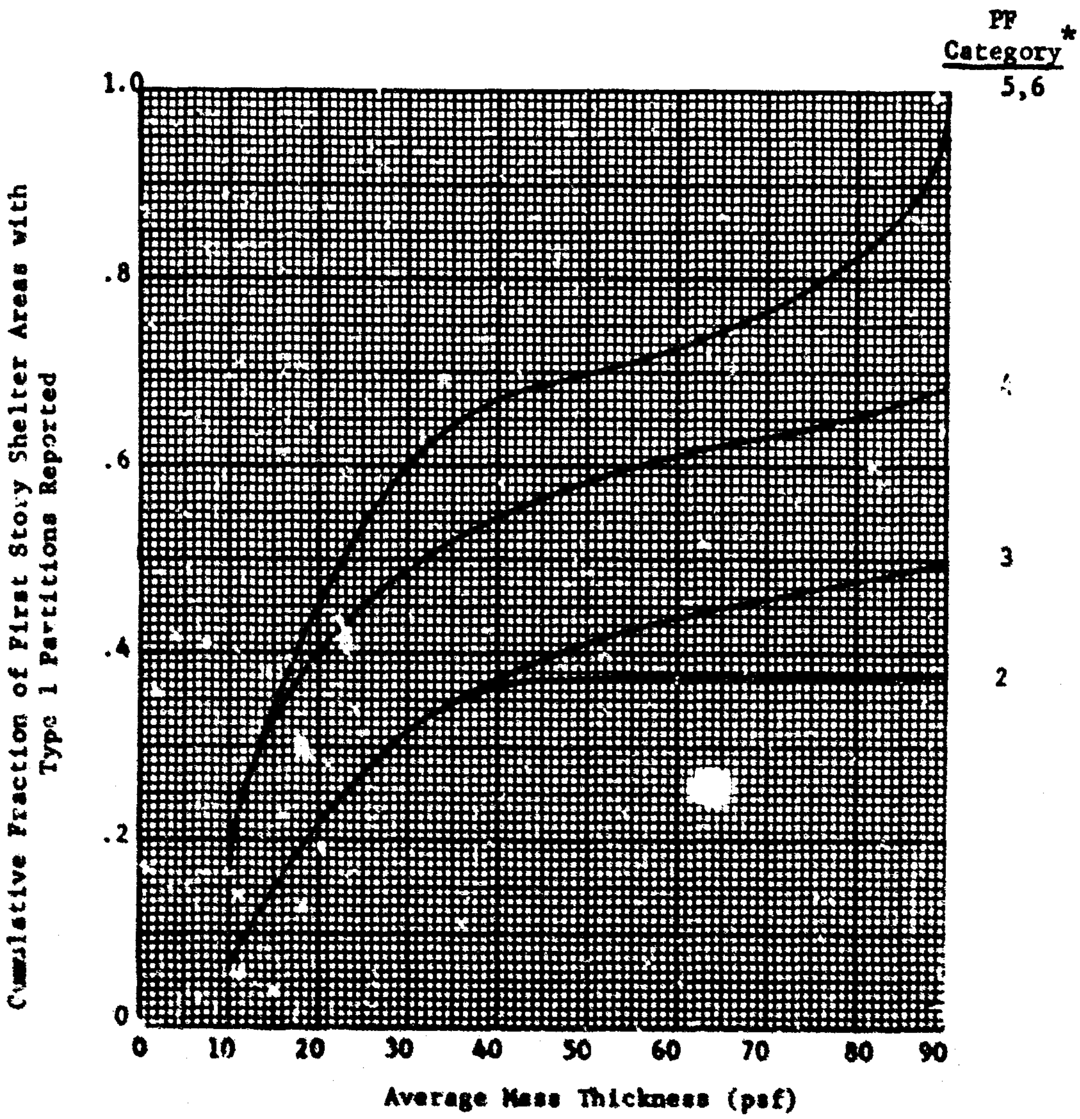


FIGURE F-19

Estimated Distribution of Type 1 Cross Partitions in First Story Shelter Areas by PF Category

(16 First Story Shelter Areas with Type 1 Cross Partitions Reported)



*No PF category 7 or 8 partitions reported.

FIGURE F-20

Estimated Distribution of Type 2 Cross Partitions in First Story Shelter Areas by PF Category
(59 First Story Shelter Areas with Type 2 Cross Partitions Reported)

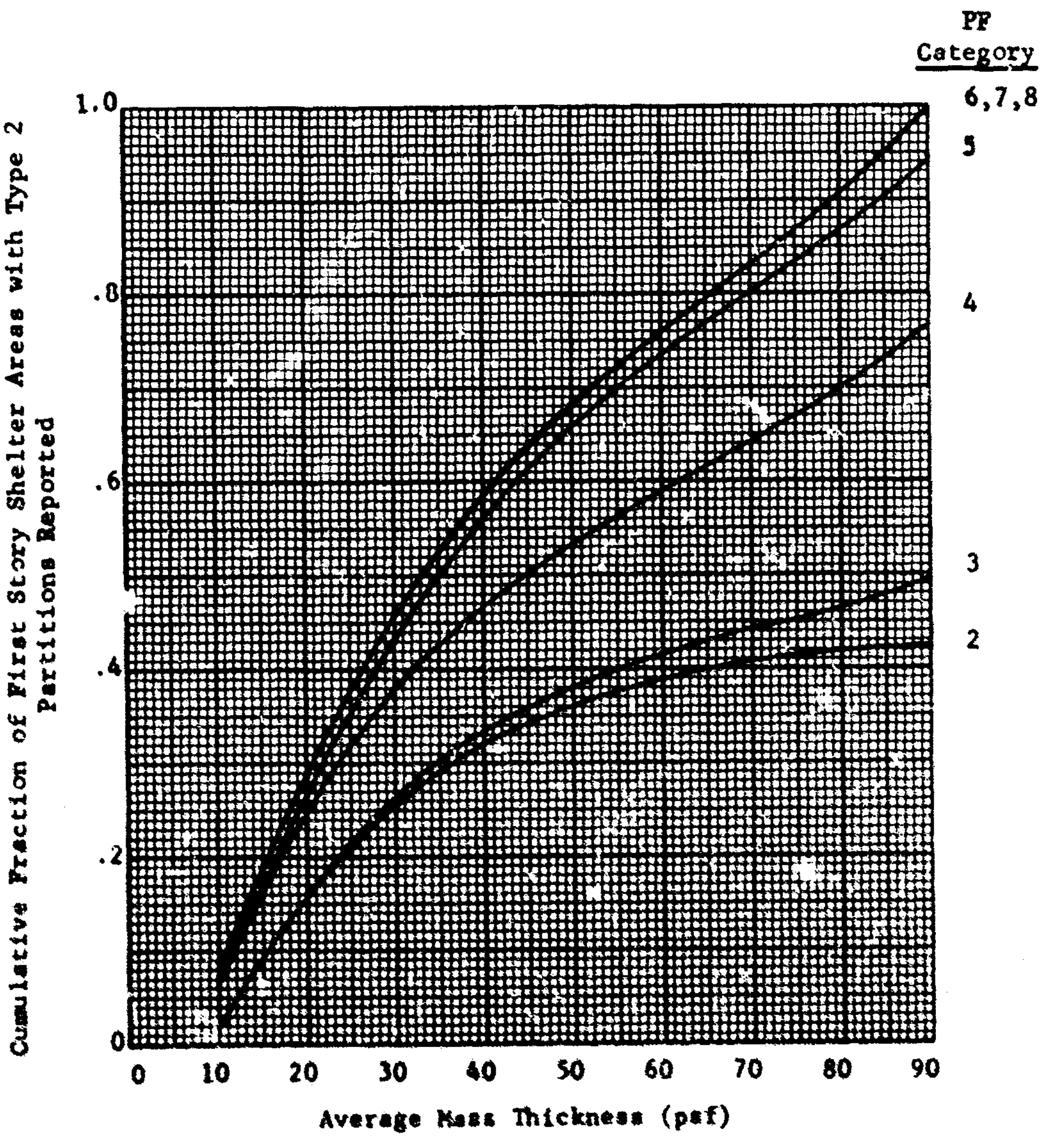


FIGURE F-21

Estimated Distribution of Type 3 Cross Partitions in First Story Shelter Areas by PF Category
(15 First Story Shelter Areas with Type 3 Cross Partitions Reported)

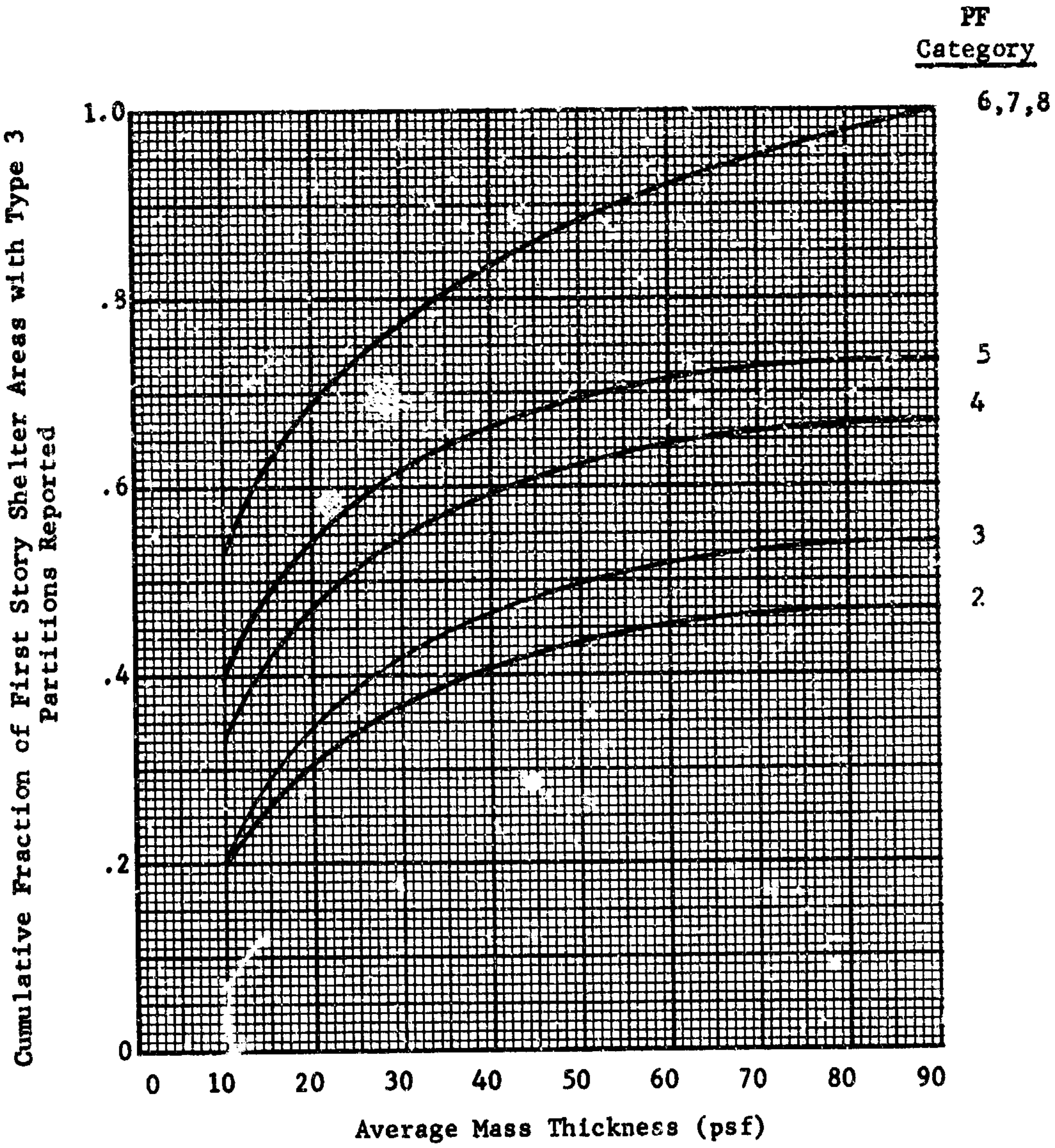


FIGURE F-23

Estimated Distribution of Type 4 Cross Partitions
in First Story Shelter Areas by PF Category
(8 First Story Shelter Areas with Type 4 Cross Partitions Reported)

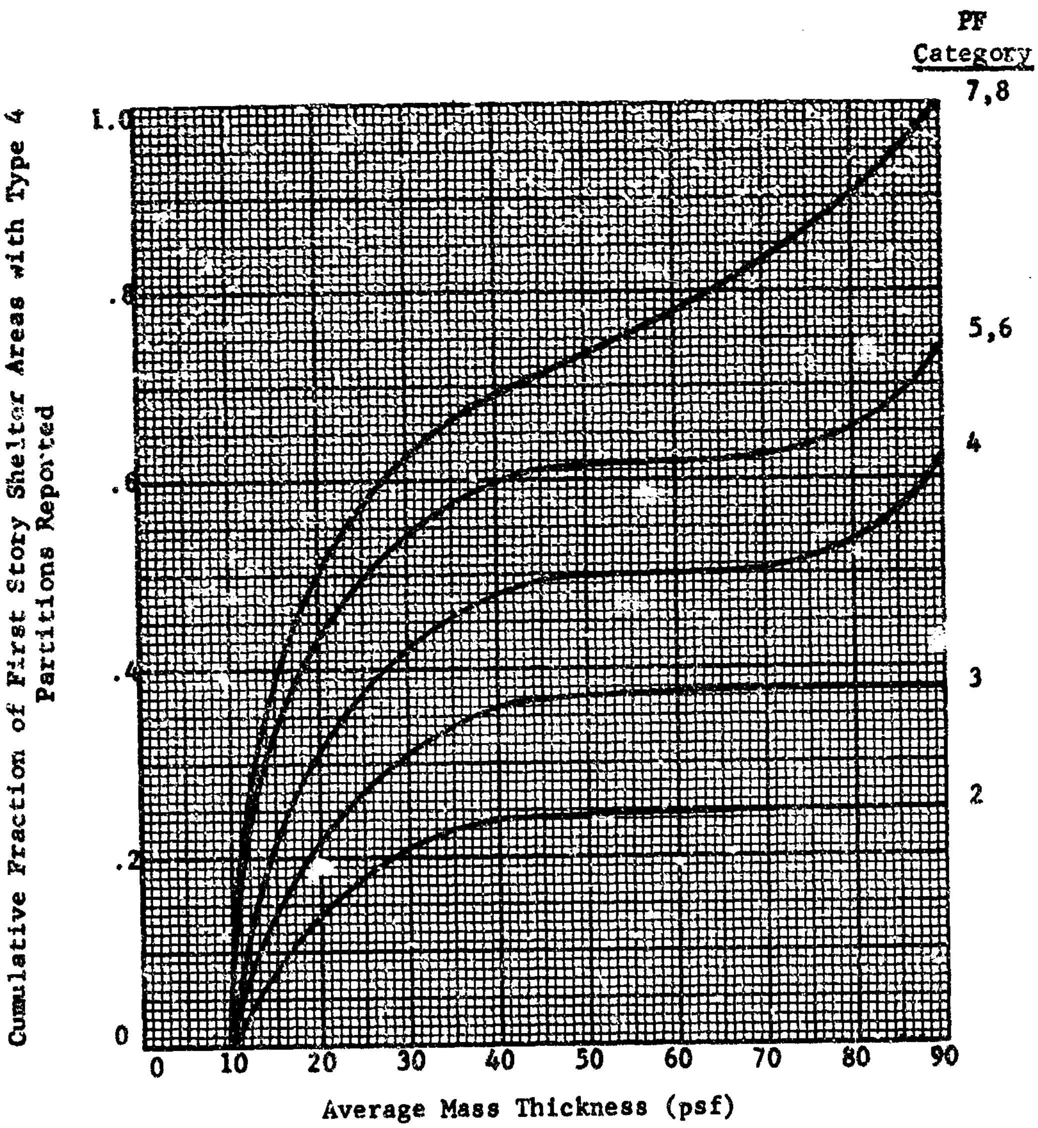
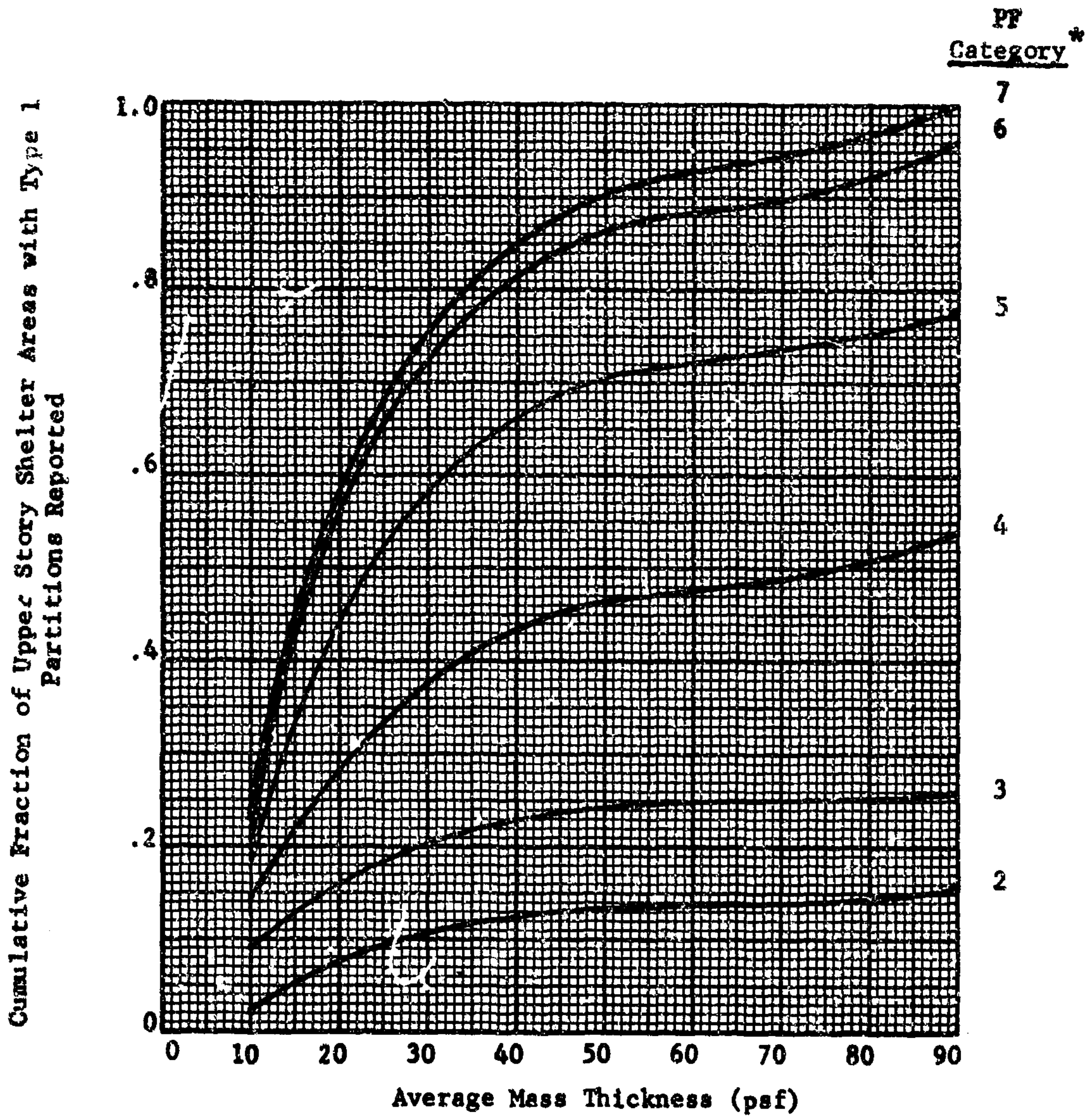


FIGURE F-23

Estimated Distribution of Type 1 Cross Partitions in Upper Story Shelter Areas by PF Category
(77 Upper Story Shelter Areas with Type 1 Cross Partitions Reported)



*No PF category 8 partitions reported.

FIGURE F-24

Estimated Distribution of Type 2 Cross Partitions in Upper Story Shelter Areas by PF Category

(176 Upper Story Shelter Areas with Type 2 Cross Partitions Reported)

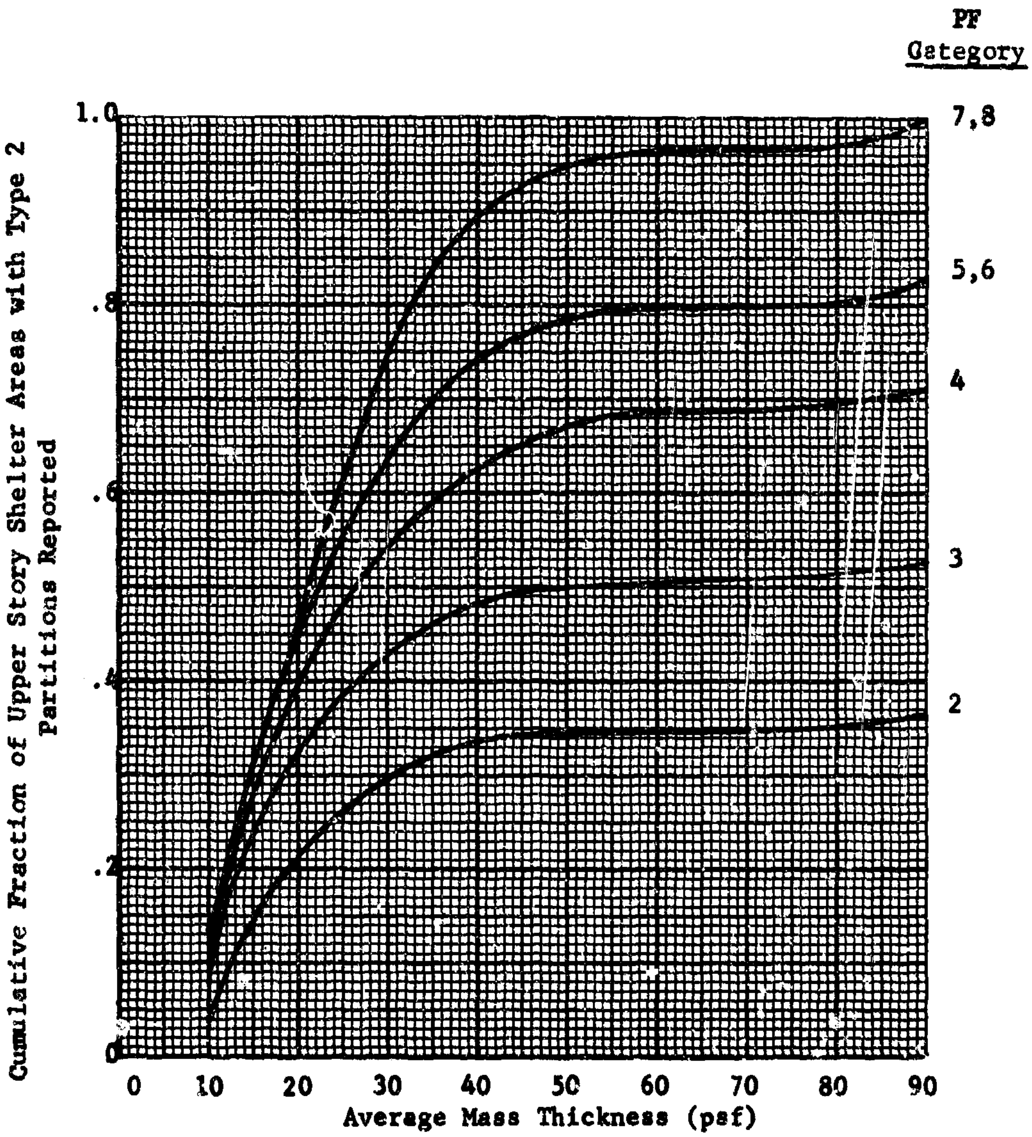


FIGURE F-25

Estimated Distribution of Type 3 Cross Partitions
in Upper Story Shelter Areas by PF Category
(38 Upper Story Shelter Areas with Type 3 Cross Partitions Reported)

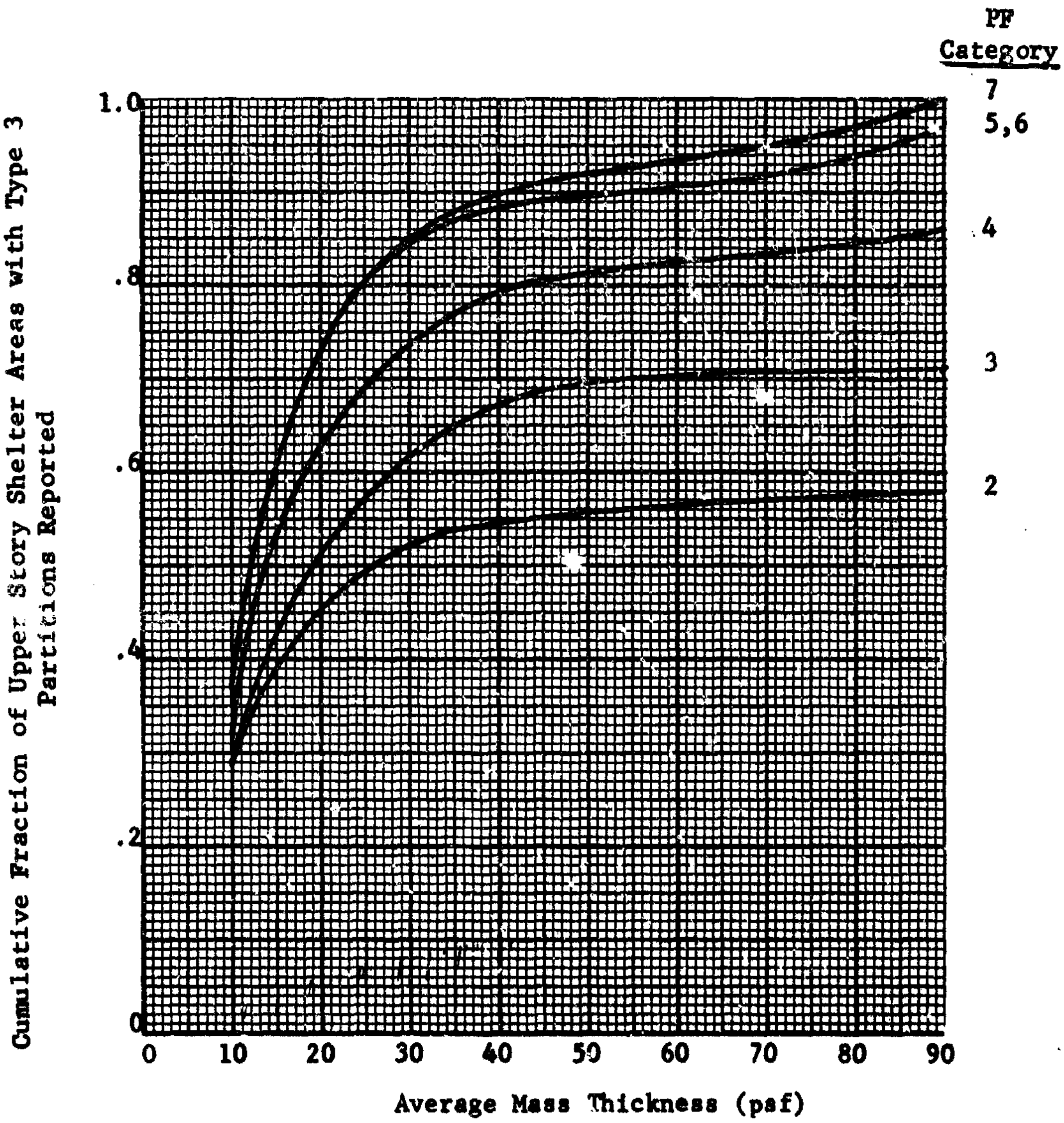
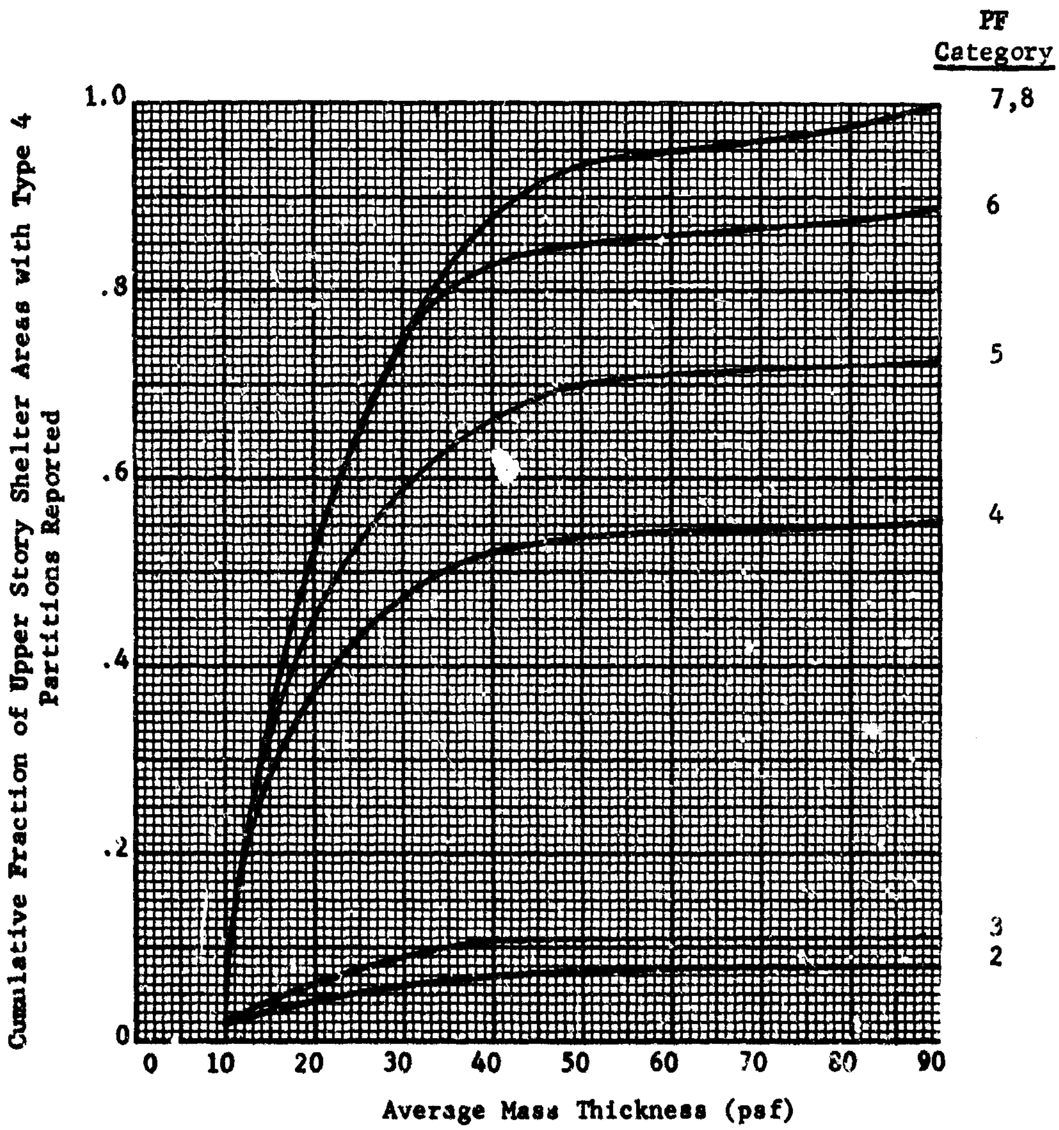


FIGURE F-26

Estimated Distribution of Type 4 Cross Partitions in Upper Story Shelter Areas by PF Category
(127 Upper Story Shelter Areas with Type 4 Cross Partitions Reported)



Appendix G

Characteristics of Buildings Used in Area Factor Computations

PF computations were made for the six points shown in Figure 6 of Chapter 5 for the fifth story of square, seven story, windowless buildings exposed to infinite planes of contamination and six combinations of ground and roof contribution. Building areas analyzed were 5,000, 7,000, and 10,000 square feet. Mass thicknesses of floors and exterior walls necessary to give center PF's of 55, 85, and 125 were determined for each of these hypothetical structures. These combinations of characteristics gave a total of 72 building configurations for which the six off-center calculations were made.

For ground contribution, using the AE Guide, a height correction factor of 0.5 was used. For roof contribution, using the Engineering Manual, the distance from the detector to the roof (Z) was 27 feet. Because there were no apertures, no floor weight correction factor was required.

The wall and overhead mass thicknesses used for given center PF's in the various sized buildings subject to combinations of roof and ground contribution were:

			Mass Thickness (psf)			
Building Area (Sq. Ft.)	Center PF	All R*	$\frac{3}{4}$ R & $\frac{1}{4}$ G**	$\frac{1}{2}$ R & $\frac{1}{2}$ G	$\frac{1}{4}$ R & $\frac{3}{4}$ G	All G
1. **Exterior Walls**						
5,000	55	-	166	133	115	103
	85	-	188	154	134	123
	125	-	203	172	153	140
7,500	55	-	158	125	109	95
	85	-	180	148	127	114
	125	-	195	164	147	133
10,000	55	-	152	120	103	91
	85	-	174	142	121	106
	125	-	189	159	141	127
2. **Overhead**						
5,000	55	95	109	124	155	-
	85	114	126	144	178	-
	125	130	142	161	191	-
7,500	55	98	111	126	157	-
	85	117	128	146	180	-
	125	132	144	162	192	-
10,000	55	100	113	127	158	-
	85	119	130	147	181	-
	125	133	145	163	193	-

*R = Roof Contribution

**G = Ground Contribution

Appendix H

Tabulated Data on the Effect of Ingress Fallout in Basements and Upper Stories

This appendix presents in tabulated form the results of the study of the effect of ingress fallout on shelters. Tables H-I through I-IV contain data for 2,000 and 10,000 square foot third stories, with and without partitions. Similar data for basements are in Tables H-V through H-VIII.

TABLE H-I

Effect of Ingress Fallout in Upper Stories

(Third Story of a 2,000 Square Foot Five Story Building Without Interior Partitions)

Case	Floor psf	Fraction of Outside Fallout Concentration				Protection Factor			
		One Aperture per Wall		50% Apertures		Center Detector		Off-Center Detector	
		Fallout Distributed Over		Fallout Distributed Over					
		Perimeter	Entire Floor	Perimeter	Entire Floor	Without Ingress	With Ingress	Without Ingress	With Ingress
1	20	.02				26	26	25	25
2	20	.20				26	24	25	24
3	20		.02			26	26	25	25
4	20		.20			26	23	25	22
5	20			.02		13	13	13	13
6	20			.20		13	12	13	10
7	20				.02	13	12	13	12
8	20				.20	13	8	13	8
9	80	.02				37	37	36	36
10	80	.20				37	34	36	34
11	80		.02			37	36	36	35
12	80		.20			37	32	36	31
13	80			.02		20	19	20	19
14	80			.20		20	15	20	15
15	80				.02	20	18	20	18
16	80				.20	20	11	20	11

TABLE H-II

Effect of Ingress Fallout in Upper Stories

(Third Story of a 10,000 Square Foot Five Story Building Without Interior Partitions)

Case	Floor psf	Fraction of Outside Fallout Concentration				Protection Factor			
		One Aperture per Wall		50% Apertures		Center Detector		Off-Center Detector	
		Fallout Distributed Over		Fallout Distributed Over					
		Perimeter	Entire Floor	Perimeter	Entire Floor	Without Ingress	With Ingress	Without Ingress	With Ingress
1	20	.02				41	41	40	40
2	20	.20				41	40	40	40
3	20		.02			41	41	40	40
4	20		.20			41	39	40	38
5	20			.02		20	20	19	19
6	20			.20		20	18	19	17
7	20				.02	20	19	19	18
8	20				.20	20	12	19	12
9	80	.02				75	75	74	74
10	80	.20				75	73	74	73
11	80		.0[illegible]			75	75	74	73
12	80		.20			75	69	74	68
13	80			.02		43	42	42	41
14	80			.20		43	36	42	37
15	80				.02	43	39	42	38
16	80				.20	43	21	42	21

TABLE H-III

Effect of Ingress Fallout in Upper Stories

(Third Story of a 2,000 Square Foot Five Story Building With Interior Partitions)

Case	Floor psf	Fraction of Outside Fallout Concentration				Protection Factor			
		One Aperture per Wall		50% Apertures		Center Detector		Off-Center Detector	
		Fallout Distributed Over		Fallout Distributed Over					
		Perimeter	Entire Floor	Perimeter	Entire Floor	Without Ingress	With Ingress	Without Ingress	With Ingress
1	20	.02				165	168	168	68
2	20	.20				165	165	168	65
3	20		.02			69	69	68	68
4	20		.20			69	64	68	64
5	20			.02		34	33	34	32
6	20			.20		34	32	34	27
7	20				.02	34	33	33	34
8	20				.20	34	25	33	26
9	80	.02				93	92	91	90
10	80	.20				93	86	91	87
11	80		.02			93	92	91	91
12	80		.20			93	85	91	85
13	80			.02		54	54	53	52
14	80			.20		54	42	53	41
15	80				.02	54	53	53	52
16	80				.20	54	36	53	40

TABLE H-IV

Effect of Ingress Fallout in Upper Stories

(Third Story of a 10,000 Square Foot Five Story Building With Interior Partitions)

Case	Floor psf	Fraction of Outside Fallout Concentration				Protection Factor			
		One Aperture per Wall		50% Apertures		Center Detector		Off-Center Detector	
		Fallout Distributed Over		Fallout Distributed Over					
		Perimeter	Entire Floor	Perimeter	Entire Floor	Without Ingress	With Ingress	Without Ingress	With Ingress
1	20	.02				77	77	77	77
2	20	.20				77	76	77	76
3	20		.02			77	77	77	77
4	20		.20			77	76	77	76
5	20			.02		45	45	44	43
6	20			.20		45	41	44	41
7	20				.02	45	45	44	44
8	20				.20	45	41	44	40
9	80	.02				192	192	189	188
10	80	.20				192	191	189	186
11	80		.02			192	192	189	188
12	80		.20			192	189	189	186
13	80			.02		111	109	109	107
14	80			.20		111	94	109	96
15	80				.02	111	109	109	107
16	80				.20	111	93	109	92

TABLE H-V

Effect of Ingress Fallout in Basements

(2,000 Square Foot Partially Exposed Basement Without Interior Partitions)

Case	Floor psf	Fraction of Outside Fallout Concentration				Protection Factor			
		One Aperture per Wall		50% Apertures		Center Detector		Off-Center Detector	
		Fallout Distributed Over		Fallout Distributed Over					
		Perimeter	Entire Floor	Perimeter	Entire Floor	Without Ingress	With Ingress	Without Ingress	With Ingress
1	20	.02				47	46	46	46
2	20	.20				47	42	46	43
3	20		.02			47	46	46	45
4	20		.20			47	39	46	38
5	20			.02		30	29	30	29
6	20			.20		30	20	30	20
7	20				.02	30	27	30	27
8	20				.20	30	13	30	13
9	80	.02				58	57	57	57
10	80	.20				58	52	57	53
11	80		.02			58	57	57	56
12	80		.20			58	47	57	47
13	80			.02		34	32	33	31
14	80			.20		34	23	33	23
15	80				.02	34	30	33	29
16	80				.20	34	15	33	15

TABLE H-VI

Effect of Ingress Fallout in Basements

(10,000 Square Foot Partially Exposed Basement Without Interior Partitions)

Case	Floor psf	Fraction of Outside Fallout Concentration				Protection Factor			
		One Aperture per Wall		50% Apertures		Center Detector		Off-Center Detector	
		Fallout Distributed Over		Fallout Distributed Over					
		Perimeter	Entire Floor	Perimeter	Entire Floor	Without Ingress	With Ingress	Without Ingress	With Ingress
1	20	.02				64	64	64	64
2	20	.20				64	62	64	63
3	20		.02			64	64	64	64
4	20		.20			64	59	64	59
5	20			.02		38	37	37	37
6	20			.20		38	32	37	32
7	20				.02	38	35	37	34
8	20				.20	38	19	37	19
9	80	.02				88	87	87	87
10	80	.20				88	85	87	85
11	80		.02			88	87	87	86
12	80		.20			88	80	87	79
13	80			.02		50	49	49	48
14	80			.20		50	41	49	42
15	80				.02	50	45	49	44
16	80				.20	50	23	49	23

TABLE H-VII

Effect of Ingress Fallout in Basements

(2,000 Square Foot Partially Exposed Basement With Interior Partitions)

Case	Floor psf	Fraction of Outside Fallout Concentration				Protection Factor			
		One Aperture per Wall		50% Apertures		Center Detector		Off-Center Detector	
		Fallout Distributed Over		Fallout Distributed Over					
		Perimeter	Entire Floor	Perimeter	Entire Floor	Without Ingress	With Ingress	Without Ingress	With Ingress
1	20	.02				125	124	125	124
2	20	.20				125	112	125	117
3	20		.02			125	123	125	124
4	20		.20			125	110	125	114
5	20			.02		81	77	81	77
6	20			.20		81	54	81	55
7	20				.02	81	75	81	77
8	20				.20	81	44	81	51
9	80	.02				140	139	139	138
10	80	.20				140	127	139	130
11	80		.02			140	139	139	138
12	80		.20			140	124	139	127
13	80			.02		90	86	90	86
14	80			.20		90	60	90	59
15	80				.02	90	83	90	85
16	80				.20	90	48	90	57

TABLE H-VIII

Effect of Ingress Fallout in Basements

(10,000 Square Foot Partially Exposed Basement With Interior Partitions)

Case	Floor psf	Fraction of Outside Fallout Concentration				Protection Factor			
		One Aperture per Wall		50% Apertures		Center Detector		Off-Center Detector	
		Fallout Distributed Over		Fallout Distributed Over		Without Ingress	With Ingress	Without Ingress	With Ingress
		Perimeter	Entire Floor	Perimeter	Entire Floor				
1	20	.02				152	151	151	151
2	20	.20				152	148	151	150
3	20		.02			152	152	151	151
4	20		.20			152	150	151	149
5	20			.02		94	93	93	91
6	20			.20		94	91	93	82
7	20				.02	94	93	93	91
8	20				.20	94	80	93	78
9	80	.02				232	232	232	232
10	80	.20				232	225	232	228
11	80		.02			232	232	232	232
12	80		.20			232	228	232	228
13	80			.02		133	131	132	130
14	80			.20		133	110	132	114
15	80				.02	133	130	132	115
16	80				.20	133	109	132	108

THE RESEARCH TRIANGLE INSTITUTE, Durham, North Carolina
OCD Work Unit 1115B - Final Report R-OU-154/196

Analysis of Survey Data, Part III (Protection Analysis of NFSS Structures). E. L. Hill, R. O. Lyday, B. W. Howard, T. Johnson, and F. A. Bryan. 1 February 1966 (UNCLASSIFIED) 190 pp.

Key facilities (electric power plants, water treatment plants, hospitals, fire stations, and communications facilities) were analyzed to identify recurring special shielding problems and to determine the importance of massive, irregular special equipment in affecting radiation shielding for certain critical operations. It was found that interior contents are significant, but only in a limited number of facilities. A computer program, written in GAT symbolic language for use on a Univac 1105 computer, for calculating the protection factor (PF) in irregularly shaped structures with numerous building construction changes was developed and is recommended for use in key facility PF calculations. A statistical study of National Fallout Shelter Survey Phase 2 building structural characteristics extracted from OCD files is reported. Included in the 844 buildings analyzed are 1030 basement shelter areas, 262 first story shelter areas, and 838 upper story shelter areas. The modal value for basement sill heights is 5 feet; whereas 80 percent of the sill heights for the first stories are from 2 to 3 feet, and for upper stories 90 percent are from 2 to 3 feet. Parallel partitions occur in 51 percent of the basement shelter areas, 68 percent of the first story shelter areas, and 78 percent of the upper story shelter areas. Cross partitions occur in 761 of the 2130 shelter areas. There were 493 areaways reported in 337 building parts. Sixty-six percent of the areaways are 30 percent or less of the building side length and 83 percent are 5 feet or less wide. "Area factors" are multipliers used to estimate the fraction of the total floor area offering protection greater than a predetermined value. The area factors used in the NFSS do not vary with structural details of the building. Several shortcomings of these approximate area factors are discussed. Analyses of shelters with only roof contribution and of shelters with both ground and roof contribution are presented. Methods of determining more nearly correct area factors for each situation are given for use with simplified hand computational procedures. Lastly, for more exact computations, it is recommended that the shelter area be calculated by computing PF's at several offcenter locations and determining graphically the areas which reach a prescribed PF. A study was made to determine the effect on the PF of a shelter of ingress of fallout particles through open windows. PF's in the basement and third story of several hypothetical buildings were compared with "effective PF's" of the same areas assuming ingress fallout. The areal mass densities of ingress fallout in the neighborhood of apertures were 2 percent and 20 percent of the fallout density outside each hypothetical building. A change in PF of 10 percent or less was noted in more than 70 percent of the 128 cases. A change in PF of 25 percent or greater was noted in only approximately 10 percent of the cases.

CIVIL DEFENSE SYSTEMS, STATISTICAL ANALYSIS, SHELTERS, CLASSIFICATION, SHIELDING, GEOMETRY, SURVEYING, DATA, BUILDINGS, NATIONAL FALLOUT SHELTER SURVEY, PROTECTION FACTOR, FALLOUT SHELTER, AREA FACTOR, PROCEDURES.

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13 ABSTRACT

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